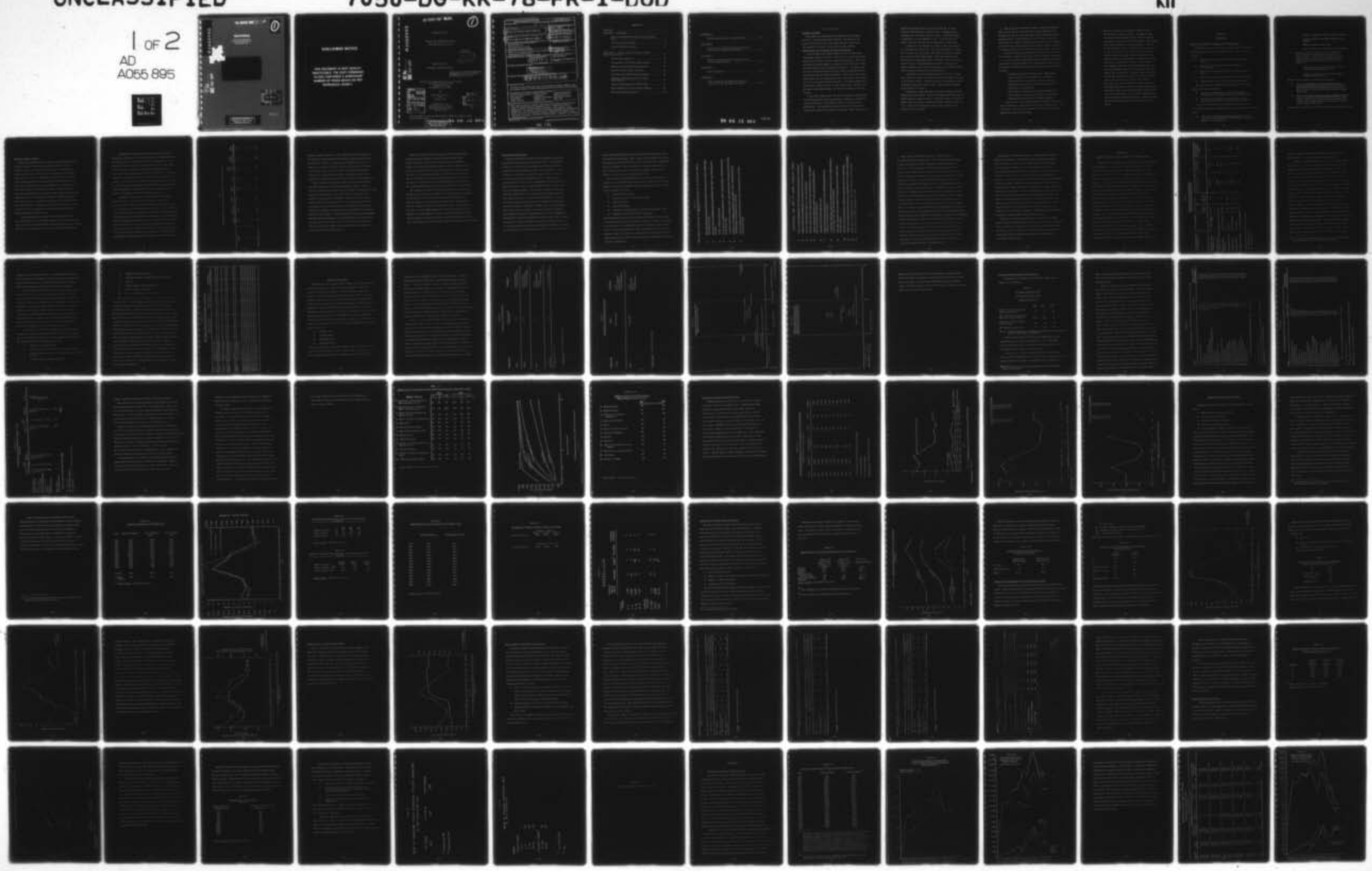
AD-A055 895 MATHTECH INC BETHESDA MD F/G 21/5
STUDY OF THE TURBINE ENGINE INDUSTRY.(U)
JAN 78 D W GRISSMER, K H KIM MDA903-76-C-0220
UNCLASSIFIED 7050-DG-KK-78-FR-1-DOD NL

1 OF 2
AD
A055 895



FOR FURTHER TRAN

1

AD A055895

MATHTECH

The Technical Research
and Consulting Division of
Mathematica, Inc.

C01942

DISCLAIMER NOTICE

FOR FURTHER TRAN

AD A055895

AD No. ___
DDC FILE COPY

January 31, 1978

Contract No. MDA903-76-C-0220

DoD-7050-DG-KK-78-FR-1

CLEARED
FOR OPEN PUBLICATION
JUN 06 1978 21
DIRECTORATE FOR FREEDOM OF INFORMATION
AND SECURITY REVIEW (OASD-PA)
DEPARTMENT OF DEFENSE

STUDY OF THE TURBINE ENGINE INDUSTRY

REVIEW OF THIS MATERIAL DOES NOT IMPLY DEPARTMENT OF DEFENSE INDORSEMENT OF FACTUAL ACCURACY OR OPINION.

Office of the Deputy Under Secretary of Defense
(Research and Engineering)
Acquisition Policy
Washington, D. C. 20310

By:

David W. Grissmer
and
Kwan H. Kim

MATHTECH, Inc.
4630 Montgomery Avenue
Bethesda, Maryland 20014
(301) 657-1610

This report does not necessarily reflect the opinions or policies of the sponsor of this study.

78 06 13 002

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) Study of the Turbine Engine Industry

5. TYPE OF REPORT & PERIOD COVERED
(9) Final report

6. PERFORMING ORG. REPORT NUMBER
DOD-7050-DG-KK-78-FR-1-

7. AUTHOR(s)
(10) David W. Grissmer ~~and~~ Kwan H. Kim

8. CONTRACT OR GRANT NUMBER(s)
(15) MDA-903-76-C-0220

9. PERFORMING ORGANIZATION NAME AND ADDRESS
MATHTECH, Inc.
4630 Montgomery Avenue
Bethesda, Maryland 20014

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Office of the Deputy UnderSecretary of Defense
(Research and Engineering)
Acquisition Policy Wash. DC 20310

12. REPORT DATE
(11) 31 January 1978

13. NUMBER OF PAGES
167

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
(12) 187p.

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
(14) 7050-DG-KK-78-FR-1-DOD

18. SUPPLEMENTARY NOTES

Two other volumes from this study: Policy Models for Surge Analysis, and An Example Analysis of DOD Procurement Policy Alternatives for Airframe

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft Engine Industry	Turbine Engines	Production Capacity
Surge Capacity	Competition	Industry Structure
Lead Times	Component Shortages	Econometric Models
Policy Analysis	Engine costs	Sales data

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a summary and analysis of original data from seven major US aircraft engine manufacturers over a time period 1960-75. Analysis of large and small engine production, surge capacity, costs, productivity, and industry structure was made and compared with historical trends and the use of econometric models. Emphasis was placed on the lead times, shortages, and roles of subcontractors, component availability, and materials.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

393 236

CONTENTS

S U M M A R Y

Statement of Problem

This report is an assessment of the structure and the capacity of the U.S. aircraft turbine engine industry. The purpose of the report is to assist the DoD in developing appropriate policies for the acquisition of aircraft turbines and for surge planning.

Characteristics of the Aircraft Turbine Engine Industry

o The Aircraft Turbine Engine market is one of the most highly concentrated industries in the U.S. with four of its seven manufacturers accounting for over 90 per cent of output in recent years. The size of the market for military engines has declined from $3.75 billion in 1966 to $2.00 billion in 1975 (in constant 1975 dollars). The market share of the two leading manufacturers (Pratt & Whitney and General Electric) has increased from 67 percent to 80 percent. This trend to fewer acquisition dollars and an increasing degree of concentration is also evident in 12 of 13 other DoD procurement categories. The leading manufacturers are obtaining a larger share of the fewer dollars spent. However, there has been no manufacturer exiting from the turbine market in the last 12 years.

o The turbine engine market consists of 6 submarkets whose products are differentiated by engine characteristics, technology, manufacturing scale and market size. Each submarket attracts a different set of manufacturers. Two submarkets have accounted for over 80 per cent of production by weight in the 1961-1975 time period. These submarkets are

turbojet and turbofan engines in the 6,000-18,000 lbs. of thrust class and 18,000-55,000 lbs. of thrust class. Although there are 7 manufacturers of turbine engines in the U.S., the maximum number of manufacturers in any submarket is four. In the two major submarkets there are only three and two manufacturers respectively.

o Production in the 1961-75 time period has been characterized by a prominent peak in 1966-1968. This peak was caused by a combination of Vietnam War surge demand, strong DoD major weapon acquisition and a peak in civilian engine demand. Since 1968, production has declined and was significantly lower in 1972-1975 than at any time in the last 15 years. Annual production in 1971-75, as measured by weight of engines, was 49 percent of production in the 1966-70 period and 75 percent of production in the 1961-65 period.

o Lead times for certain component parts have varied over time, with shortest lead times in the 1963-1967 period and longest lead times in the 1971-1974 period. Typically lead times for controls was around 11 months in 1965 and 15 months in 1973. Overall engine lead times varied from 10 to 21 months.

o Employment of production workers and output during the 1961-75 period were closely related. The average production in 1961-75 was 14.8 million pounds of engines annually. The marginal number of production workers required to produce an additional million pounds of engines was 1730. A much weaker relationship exists between engineering and managerial staff and output.

o Labor productivity measured by pounds of engine per production worker over the 1961-75 period shows that the peak productivity of 315 pounds per year per production worker occurred during the 1966-68 production period. Current productivity is the lowest in the time period and is less than 175 pounds per worker per year. Large amounts of subcontracting during the peak 1966-68 period may inflate somewhat the apparent productivity of workers in the industry during that period.

o Although turbine engine production has decreased by 49 percent, data available on industry floor space shows no significant contraction.

o A rapid increase in production occurred in the 1965-1967 period, rising from 13.4 million pounds to 25.2 million pounds. Study of data in this period provides the following insights into production in terms of surge.

- o A significant part of the turbine engine industry surge capacity depends on the subcontractors. It appears, from limited data, that the make buy ratio shifts from around 50/50 in periods of non-peak production to 30/70 in periods of peak production.
- o Third shifts in periods of surge become 15-25 percent of the workforce as compared to 5-15 percent in other times. Second shift utilization does not change drastically.

o Surge capacity is the maximum production capability with present plant and equipment, assuming unlimited labor and material supplies. The calculation of this surge capacity however is imprecise with no one method being completely satisfactory.

- Historical periods of peak production (1967-8) can be taken as proven production capacity. Assuming no change in capacity and plant between 1968 and 1975, and the same subcontractor capacity, estimates can be made of the relationships of peak production to present production. The ratio of 1975 produciton to peak year production for the industry as a whole is 1/2.6 or .38. Because military production constitutes about 50 percent of current production, surge military production could potentially be increased by about 500 percent based upon this estimate. This percentage varies among the different turbine engine submarkets. For very large turboshaft engines ($\geq$ 2000 hp) and turbojet engines (18-55 thousand lbs. of thrust), surge ratios (1975 to peak year production) are about .5. For smaller engine markets the surge ratios are in the .15 to .5 range.
- Historical surge rates can also provide some estimates of what performance might be expected in times of future surge. From 1965 to 1967, total industry production increased from 13.4 to 25.1 million lbs., a rise of 90%. Individual companies experienced production increases of from 60% to 300% in terms of maximum production increase over a two year period.

CHAPTER I

Introduction

Summary of MATHTECH Analysis of the Industrial Base

At the initiation of the present contract, DoD had several concerns which prompted their study of the industrial base. These concerns included:

- Apparent declining industrial base in the subcontractor industry,
- Inability to meet surge demand in recent past for selected items,
- Increasing unit production costs of certain procurement items,
- Apparent over-capacity in certain defense industries, and
- Apparent lower rates of return for defense contractors.

The expressed need to MATHTECH from the point of view of the analysis to be done was twofold:

- To develop analytical tools capable of addressing the questions concerning industrial base surge capacity, and
- To analyze surge capacity in two industries--turbine engine and missiles (later changed to airframe industry).

In response to the first task, MATHTECH's work in the area of developing and applying analytical tools to the surge problem is summarized below.

- The report, Policy Models for Surge Analysis, contains work on four models developed to apply to the surge capacity problem. These models are:

- A long run equilibrium model of a defense industry,
- Inventory production scheduling model for surge capacity,
- Industry simulation model, and
- Penalty contracting to meet surge capacity demand.

- Appendices B and C of this report contain additional models and analysis applicable to the general surge capacity problem. These models are applicable to the airframe or aircraft turbine industry using available published data as initial examples of analysis. These models are:
  - Economic concentration and capacity utilization in the aircraft engine industry, and
  - Impact of competition on new capacity buildup in the aerospace industry.

Our work on the second task is summarized as follows:

- A report, An Example Analysis of DoD Procurement Policy Alternatives for Airframes, contains application of the long run equilibrium model to the airframe industry. Data used in the model was collected by Systems Planning Corporation.
- This report, Study of the Turbine Engine Industry, contains results of initial analysis of data collected by MATHTECH from the turbine engine industry on historical production, employment, capacity and productivity experience of seven turbine engine manufacturers.

This report is the last of three reports under Contract MDA 903-76-C-220.

The Surge Capacity Problem

The problem addressed in these reports is that of developing defense procurement policies which maintains an industrial base capable of expanding to meet surge demand while at the same time maintaining efficient peacetime unit production costs and technological superiority. These objectives are often conflicting and improved policies in this area require difficult judgments concerning tradeoffs between the degree of risk assumed in failing to meet surge production vs. minimizing peacetime defense budgets. The effects of the policies adopted also go far beyond defense budgets since the industries under study provide substantial employment in the U.S. economy and contribute a significant portion to U.S. exports overseas. Technological superiority in the civilian sector has often followed from developments made in the military sector. Thus in the long run, the competitiveness of U.S. industry could depend on policies adopted in the defense sector.

Surge demand for war material can arise either from direct involvement of U.S. forces or through supplying of U.S. material to allies. There are only two fundamentally different strategies with respect to meeting the needs for surge demand: inventory and surge production capability.

The problem is to determine what mix of inventory and surge production is appropriate for each item in demand. The appropriateness of inventory policy or surge production policy is dependent on several parameters characterizing the nature of the item, nature of the conflict and various costs. Table 1.1 sketches the rough dependence of the nature of the surge demand policy on specific characteristics. Inventory will tend to be the appropriate policy when the duration of the expected conflict is short, attrition rates high, lead time for production are long, etc. Maintaining surge production capacity will be the appropriate policy when the duration of expected conflict is long, rate of technological improvement is high, lead time for production is short, etc.

Appropriate surge demand procurement policies will depend on the characteristics of the item under consideration, nature of the expected conflict and the degree of risk implicitly assumed in a stockout cost. The major tradeoff in actually deriving policies for surge production is the extent to which the policymaker wants to minimize current budgetary costs (peacetime costs) as opposed to decreasing the risk associated with not meeting possible surge demand. A large uncertainty exists in some of the key parameters necessary to determine appropriate surge policies. For instance, the timing and intensity of conflict as well as technological rate of improvement are subject to great uncertainty. Before rational surge planning can take place, these uncertainties must be removed by

Table 1.1

Rough Dependence of the Nature of the Surge Demand Policy on Specific Characteristics

	Duration of Conflict	Item Attrition Rates (Conflict Intensity)	Lead Time for Production	Cost of Shortage (Stockout Cost)	Inventory Cost	Peacetime Surge (Idle) Capacity Costs	Item Rate of Technological Improvement	Item Rate of Deterioration
Inventory	Short	High	Long	High	Low	High	Low	Low
↕	↕	↕	↕	↕	↕	↕	↕	↕
Industry Surge Production	Long	Low	Short	Low	High	Low	High	High

military or political judgment. These judgments are usually implicitly incorporated in specification of threat scenarios, which specify the type and intensity of conflict. Given the nature of the threat scenarios, the particular mix of war material that would be used in wartime, the timing of the conflict, and priorities with respect to preactime budgets and wartime risks, surge procurement policy specifying an industrial base configuration and appropriate inventory policy could be rationally defined.

There will always be controversy with respect to the basic political and military judgments from which surge policies originate. However there are aspects of surge policy which can profitably be studied from strictly a management perspective - namely, *the coherence, consistency and* flexibility of surge procurement policies. One major objective of surge analysis should be to determine whether procurement and surge policies are consistent over major defense items. Specifically, is the degree of risk inherent in adoption of inventory positions and industrial base policies the same across all items? It would be possible to develop general policies and DoD guidelines specifying surge demand policies across procurement categories and services which more or less assume the same levels of risk for a given threat scenario and make the same set of assumptions concerning other important parameters.

Another major objective of surge analysis is to determine whether current procurement policies encourage the type of industrial base desired, and whether these procurement policies have responded to changes in key parameters such as technology, threats, and the economic environment (production costs, capacity costs, profits, etc.) over time. The nature of the surge demand policies and the industrial base should change as changes occur in the important parameters listed in Table 1.1. For instance as weapons become more complex and lead times lengthen, more emphasis should be put on inventory as opposed to surge production.

The question of coherence between procurement policies and the type of industrial base desired is a critical one. The industrial base is shaped by both market forces as well as DoD procurement and R&D policies. Defense contractors may find lucrative civilian markets and quit defense business. Shaping of policies toward the industrial base has to be done in the context of a sound understanding of the industrial dynamics in a given industry. This understanding can only come about through detailed examination of historical industry data, extensive dialogue with industry managers, and an understanding of the technological trends and market forces in the industry.

Current DoD Surge Planning

The effort within DoD currently to ensure adequate surge capacity is currently directed primarily at microlevel issues. Currently data is collected at the item level from prime and subcontractors which estimates the level of production possible in a surge situation. Work is also done to determine item criticality and priorities. There are severe problems with this kind of data, however. Estimates are collected on only one item at a time, independent of other wartime and peacetime demand. Also, the original vendor and subcontractor is the only one providing such data. In times when economic conditions and the defense industrial base is relatively stable, such planning at this level, appropriately done, can provide useful information. However, as economic conditions and the stability of companies in the industrial base become subject to increasing variability, then increased planning at the macro-level is necessary. Our concern shifts from whether a given company can provide an individual item to how many companies of this type will be in business and what their likely response will be to surge requirements. Macro-level planning is especially important in an era of a contracting industrial base when the condition of individual contractors and subcontractors is especially unstable. There are also several current

issues in defense planning which require improved consideration of macro-level industrial base planning. These include foreign military sales, NATO standardization and interoperability, access to raw materials, and declining procurement dollars. Table 1.2 provides a summary of trends or issues which, I think, would argue for increased emphasis on industrial base planning at the macro-level rather than micro-level.

What are the tools defense planners can use to help shape industrial capacity to meet DoD objectives at a macro-level? DoD can effect changes through either procurement policy changes or procurement awards. Major procurement policy areas are:

1) Regulated profit margins,

2) Timing and amount of procurement awards,

3) Payment policies,

4) Type of contracting,

5) Regulations requiring industry monitoring and reporting, and

6) Allowable costs and other ASPER regulations.

The organizational problem is how to incorporate explicitly surge planning concerns into decisions that are routinely made in these areas. One solution is to expand the current responsibility of DoD groups doing industrial base work. Such a group would have the added responsibility for macro-level planning. Table 1.3 sketches some of the missions and characteristics of a surge planning group. While many of the points are straightforward, comment on a few are appropriate.

Table 1.2

WHY MORE ATTENTION TO MACROPLANNING OF INDUSTRIAL BASE

1. Declining defense procurement dollars makes it necessary to replace market power with better planning
2. Declining defense peacetime procurement dollars also make surge planning more essential
3. Foreign military sales issues
4. In an era of contracting (as opposed to stable) industrial base, important decisions are at macro level.
5. Industrial dynamics, business cycles play important role in shaping industrial base
6. Question of international industrial cooperation (NATO interoperability and standardization) will become more important
7. Need to develop coherent rationale for shape of industrial base in different procurement areas

Table 1.5

ADVANTAGES AND ROLE OF SURGE PLANNING GROUP

1. Focus on peacetime/wartime transition planning and peacetime surge levels
2. Develop longer term relationships with defense industry personnel and COTR
3. Produce industrial base impacts for major procurements
4. Periodic review of procurement policies and relationship to surge capacity
5. Develop consistent balanced inventory and surge production policies across services and war materials
6. Repository of industrial data over time
7. Capable of attracting excellent analyst due to challenging problem and emphasis on industrial dynamics
8. Coordination with other government agencies collecting industry data (Commerce, Census, Labor, SEC, FTC) and industry groups
9. Anticipate industrial base contraction through procurement schedule and financial analysis
10. Definition of set of consistent, balanced surge levels by procurement areas
11. Initial concentration on one industry and subcontractors to provide a model analysis
12. Coordination of foreign military sales and industrial base concerns
13. Coordination of NATO/US procurement issues

Major procurement decisions can have a critical impact on the configuration of the industrial base. These decisions not only impact a single weapon system but the configuration of the industrial base in future years. Since major procurement decisions are critical to the formation of the industrial base, assessment of the effect of various procurement options on the industrial base would seem appropriate. Individual procurement decisions are made on the basis of technical design, cost, and political considerations, however, concerns for the industrial base are present in almost every major decision. Formalization of these concerns in the form of industrial base assessment statements would allow a more formal review of the direction a given award would lead in terms of industrial base studies. These assessments appear to be critical in the next 5-10 years since contraction of the industrial base in several areas appear likely. The number of major awards from DoD is declining in most procurement areas, thus the role of individual awards will be to partially determine what companies will be viable defense contractors. Longer term considerations should systematically be input into these procurement decisions so that the resultant industrial base after contraction will match the defense needs of the nation. These assessments need to be built on a sustained period of data collection and analysis from the industry under question. Much of the data needed to perform such an analysis would be easier to collect at the point of a major procurement decision since some of the data is routinely forwarded as part of the proposal process.

The absence of good historical data is a major impediment in doing industrial base analysis. Data is likely to take a long time to gather in these studies due to the decentralized nature of subcontractors and the fact that defense manufacturers are increasingly becoming part of large corporations doing significant nondefense work. Thus data routinely available from companies is not useful for analysis of specific defense divisions. Data becomes highly valuable and needs systematic and sustained collection over time. Another factor is the proprietary nature of the data collected which mandates that data being collected by an outside contractor. Companies are less likely to reveal certain data directly to the government. Some improvements in data could be obtained through closer cooperation with other federal data gathering agencies (FTC, Census, Labor). Some additions to such surveys as the annual survey of manufacturers, as well as specification of alternate data breakouts would greatly improve the usability of this data for defense purposes. It would also minimize the need for industry to provide additional data to the government.

The nature of the study effort would seem to argue for a combined inhouse and out-of-house effort where the out-of-house effort is a sustained effort at studying several industries having similar characteristics. The out-of-house contractor would be responsible for industry data collection and modeling, while the inhouse team would collect DoD data and be responsible for policy review.

CHAPTER 2

Analysis of Data From Seven Turbine Engine Manufacturers

The focus of this chapter is the seven turbine engine manufacturers in the United States. These turbine engine manufacturers are listed in Table 2.1 together with their parent companies, characteristics and military engine sales in FY 75. The study does not include airplane piston engine manufacturers, nor does it consider foreign producers of turbine engines. Foreign producers and subcontractors with the possible exception of Rolls Royce of Great Britain have historically played a relatively minor role in U.S. military turbine engine production. However, in 1975, Rolls Royce had 17 million dollars engine sales to DoD. This amount is greater than three of the U.S. manufacturers. In recent years, joint engine development and production agreements between U.S. and NATO country manufacturers have also been initiated. These agreements are mainly the results of the expanding NATO and world markets for weapon systems. U.S. companies are more competitive in these markets when teamed with producers from other countries. This report covers only the surge production capacity of U.S. producers of military turbine engines and DoD policies relevant to surge capacity of these companies. The scope of the current contract limited our initial work to U.S. turbine engine producers only. As joint ventures between foreign and U.S. manufacturers increase, future studies of surge capability will have to

Table 2.1

Turbine Engine Manufacturers and Parent Company Characteristics

U.S. Turbine Engine Manufacturers	Parent Company	Parent Company Sales		Estimated Aerospace Division Sales (1975) (Millons $)	Military Engine Sales FY75 (Millions $)	Percent Military Engine Sales of Total Company Sales
		FY75 (Millons $)	Rank in Fortune 500 (1975)			
Pratt and Whitney Aircraft Group	United Technologies	3878	40	2182 1/	1056	27
General Electric - Aircraft Engine Group	General Electric	13399	9	1972 2/	544	4
Detroit Diesel Division	General Motors	35724	2	292	219	1
Lycoming Division	AVCO	608	285	N/A	40	7
Garrett Corp.	The Signal Co.	N/A	97	632 1/	12	N/A
Teledyne (CAE)	Teledyne	1715	115	N/A	12	1
Williams Research	Williams Research	N/A	-	N/A	10	N/A

1/ Standard and Poor's.

2/ Annual Report.

include a complex set of questions dealing with the possible role of foreign producers in meeting wartime surge requirements.

With the exception of Williams Research, U.S. manufacturers of turbine engines have parent companies listed among the largest 300 companies in the U.S. Military turbine engine sales in FY 75 represented a varying fraction of total company sales. Williams Research is a relatively small company with almost all of its business in the engine sector. Pratt and Whitney constitutes about 27 percent of sales for United Technologies. For each of the remaining companies, military turbine engine sales represented probably less than 10 percent of total company sales. This corporate arrangement differs significantly from airframe manufacturers where military aerospace sales constitute significant proportions of total company sales for companies like McDonnell Douglas, Boeing and Lockheed. One effect of the corporate environment for turbine engine manufacturers is that specific data for turbine engine operations is unavailable through the standard industry data sources (annual reports, SEC Form 10 K, Standard and Poor's, etc.) where data is provided by company.[1/] Data provided by the companies to the government in the annual survey of manufacturers is of some value in doing an analysis of the industry. However the SIC category which contains airplane turbine engines also contains piston engines

1/ If recent proposed changes in company reporting procedures by the SEC are adapted, divisional data would be reported.

and other engine components and parts. Another problem with this data is that much of the data collected cannot be reported due to the dominance of two of the manufacturers. A study of the turbine engine industry is thus heavily dependent on data voluntarily supplied by companies.

In the period 1961-1975, there has been only one *new entrant into* the turbine engine sector. Williams Research Corporation, although started in 1954, has achieved significant sales during the late 60's and early 70's. Williams' successful entrance is due mainly to technological competitiveness in the very small turbine engine market. There have also been no exits from the turbine engine sector since the late 50's and early 60's. Curtiss Wright and Boeing were the last companies to exit from the sector. Turbine engine manufacturing was phased out in the late 1950's for these companies. Thus in the 1960-1975 period, the number of companies have remained relatively stable.

To collect data, a survey was formulated and sent to the turbine engine divisions of the seven companies listed in Table 2.1. A copy of the survey is provided in Appendix D. The data requested was historical data from 1961-1975 in the following general areas:

1. Turbine engine production data
2. Turbine engine characteristics for each engine produced
3. Sales data broken by source of sale (government, commercial, foreign)
4. Lead time data by component and engine

5. Employment and earnings data

6. Capacity data (value of buildings and machine tools)

7. Cost data

8. Foreign suppliers and subcontractors

9. Future expected environment

10. Research and development expenditures.

The survey was sent out in November, 1976. Response to the survey was non-uniform. A single company refused to provide any data, while 3 companies provided near complete data sets. Three other companies provided partial data. The time between the initiation of the survey and the time when final voluntary company data was received was almost a year. Once it became clear which data companies were going to provide, supplemental data requests were forwarded to the Air Force Aeronautical Systems Division at Wright Patterson Air Force Base. Some of the missing data not provided voluntarily by the companies was filled in by the Office of Procurement and Manufacturing at Wright Patterson. Table 2.2 shows the status of data collection on the different survey tables. Rather complete data has been compiled on Turbine engine production in the 1961-1975 period. Excellent data is also available on lead times, capacity and employment. Generally, the data on sales and cost structure was withheld by companies and breakouts were not available in the detail desired. This data from industry was supplemented by historical DoD expenditure data from the DoD procurement data base. The following sections constitute an initial analysis of the collected data.

Table 2.2

Data Collection Status for Turbine Engine Manufacturers

		Complete Data-No. of Manufacturers	Partial Data-No. of Manufacturers	No Data-No. of Manufacturers
Table 1	Historical Annual Engine Production	7	0	0
Table 2	Engine Characteristics	7	0	0
Table 3	Lead Times for Engine Types	5	0	2
Table 4	Lead Time for Critical Items	5	0	2
Table 5	Sales Data for Engines	3	4	0
Table 6	Sales Data for Spares, Rebuilding and Modification	3	2	2
Table 7	Sales Backlog Engines	2	3	2
Table 8	Sales Backlog Spares, Rebuilding and Modification	2	2	3
Table 9	Projected Sales	4	3	0
Table 10	Capacity	5	2	0
Table 11	Employment	4	2	1
Table 12	Capacity	6	1	0
Table 13	Cost Structure	2	2	3
Table 14	R&D Funds	3	0	4
Table 15	Foreign Suppliers	5	0	2
Questions	Future Business Environment	5	0	2

Turbine Engine Markets

There does not exist a single market for turbine engines in the economic sense that the products are standardized or homogeneous. Rather there are several markets whose products are differentiated by engine characteristics. Based on turbine engine production data from 1970-75, we have identified turbine engine classes characterized by groups of companies that compete within an engine class. These classifications are based on actual production of engines, but do not include engines currently in research or development. Several companies currently are attempting to enter new markets through engines in development. Two dimensions account for most of the product differentiation among turbine engines - Power class and engine type. There are 4 basic engine types characterized by the output stage of the turbine engine. These are:

1) turbofan engines
2) turbojet engines
3) turboprop engines
4) turboshaft engines

Within each engine type, engines differ by power class. There appear to be at least 6 separable products within the turbine engine group where there exists sufficiently different engine technology, manufacturing scale, and

market size to attract different turbine engine manufacturers. Table 2.3 groups turbofan and trubojet engines and distinguishes producers on the basis of 4 engine power classes. Table 2.4 groups turboshaft and turboprop engines and distinguishes 2 power classes. Although there are seven nominal producers of turbine engines, the largest number of companies competing within an engine submarket is four. The markets that have the largest number of producers are the power classes within the turboshaft, turboprop market and the medium and small turbojet and turbofan engine markets. The large engine turbojet, turbofan markets has only two producers, General Electric and United Technologies, while the very small turbojet engine market has only a single producer, Williams Research.

The turbine engine producers differ in their degree of specialization among turbine engines. Figures 2.1 and 2.2 illustrate the range of each manufacturers' product line in the turbojet and turboshaft market. Among turbine engine companies, General Electric and United Technologies have the broadest product line. G.E. produces engines in 5 of the 6 submarkets. G.E. differs from United Technology in terms of product line mainly by having a significant part of the turboprop, turboshaft markets. United Technology through 1975 did not produce in the small turboshaft engine market, but otherwise has engines in 4 of the 6 submarkets. The other producers are more highly specialized in product. Detroit Diesel has engines in 3 of the 6

Table 2.3

Turbofan and Turbojet Markets

Engine Type	Thrust Range [1/] (000) lbs.	Companies
Large	18-55	General Electric United Technologies
Medium	6-18	Detroit Diesel General Electric United Technologies
Small	.5-6	Garrett General Electric Teledyne United Technologies
Very Small	0-.5	Williams Research

1/ Maximum power @ S.L.

Source of Data: MATHTECH survey data.

Table 2.4

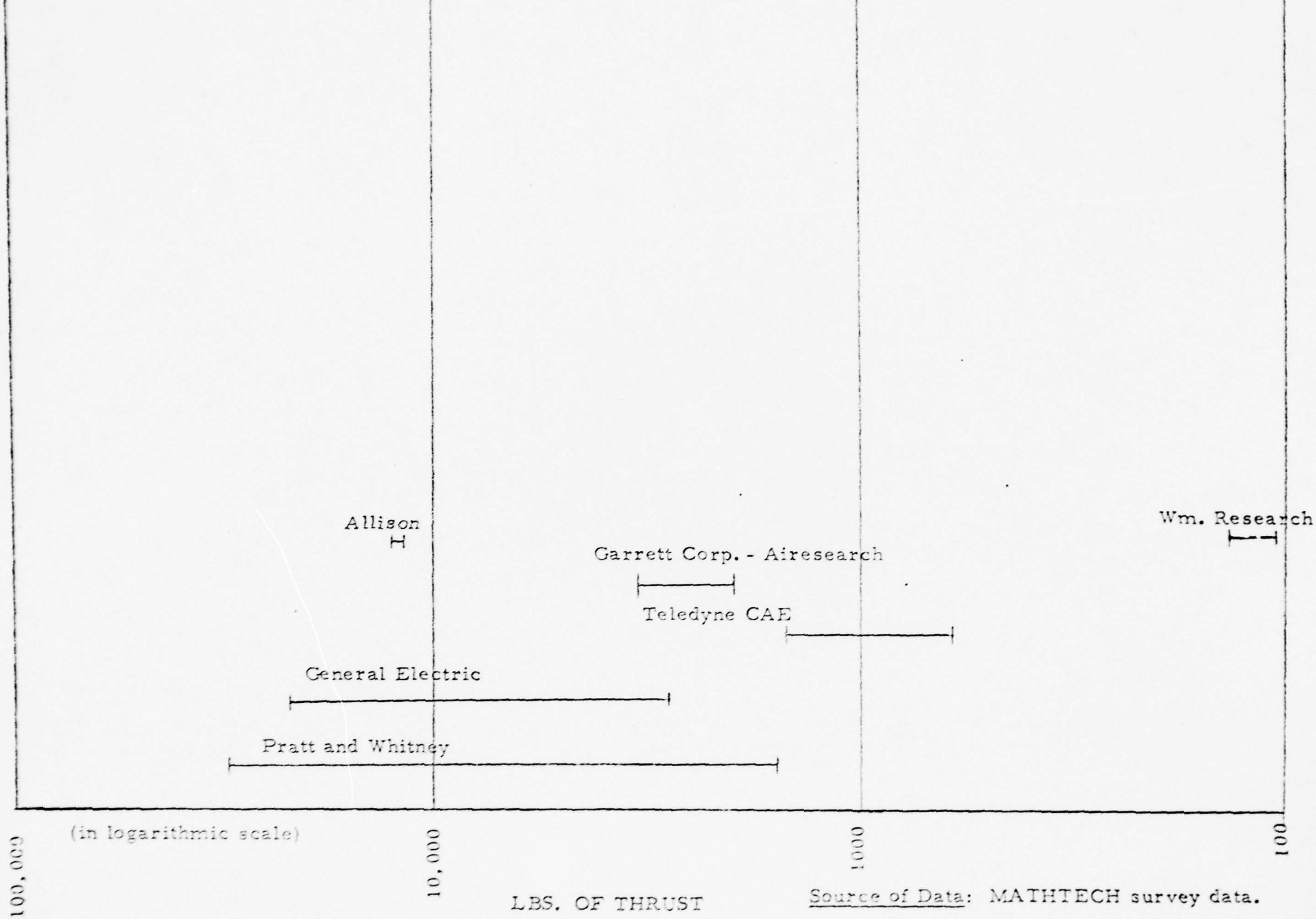
Turboshaft and Turboprop Engine Markets

Engine Type	Power	Companies
Large	2000-5000 SHP	AVCO General Electric Detroit Diesel United Technologies
Small	0-2000 SHP	AVCO Detroit Diesel Garrett General Electric

Source of Data: MATHTECH survey data.

Figure 2.1

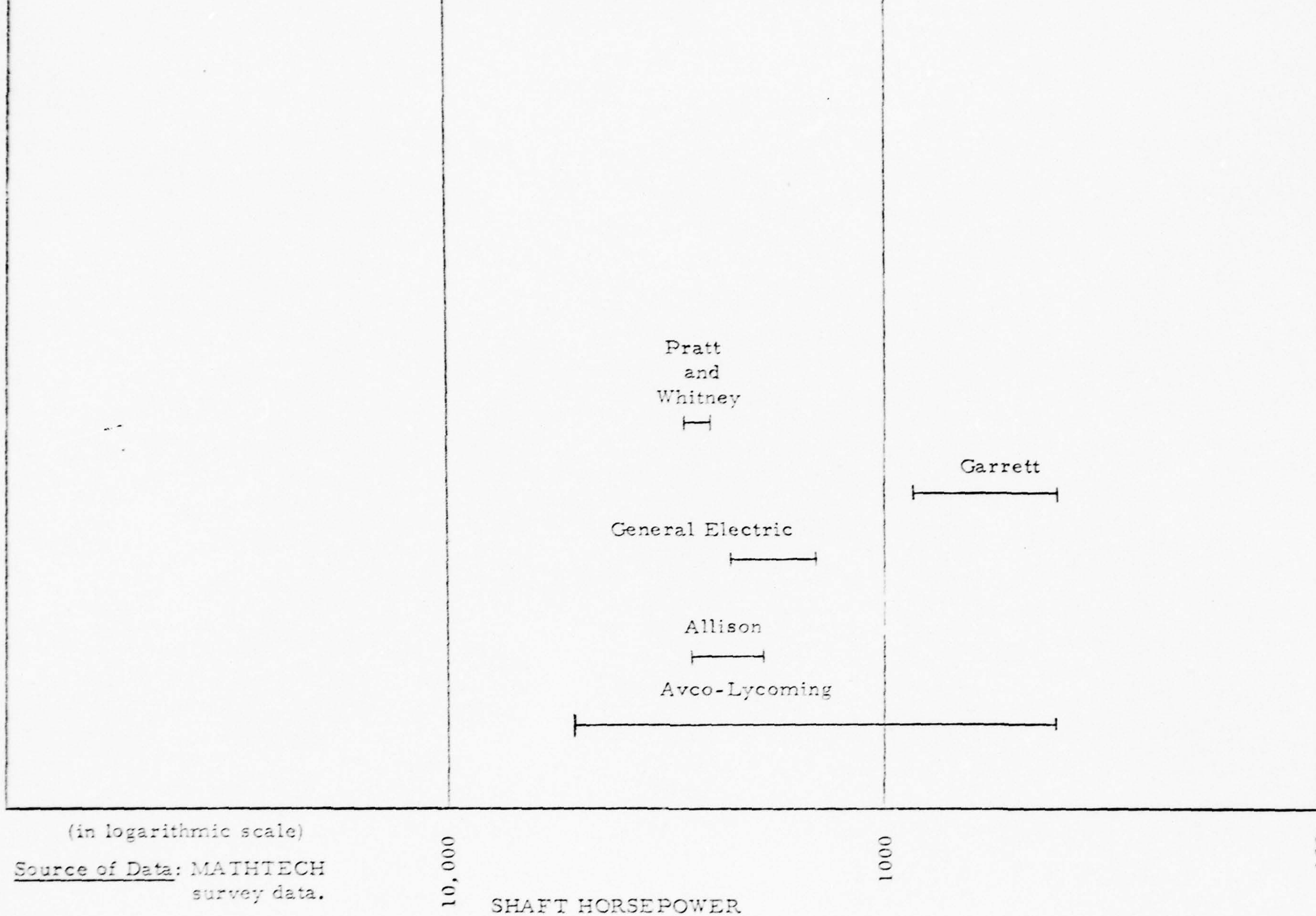
Range of Turbojet, Turbofan Engine Production in Lbs. of Thrust



Source of Data: MATHTECH survey data.

Figure 2.2

Range of Turboshaft, Turboprop Engine Production in Shaft Horsepower for Leading Manufacturers



(in logarithmic scale)

Source of Data: MATHTECH survey data.

submarkets, but its main volume is in the turboshaft, turboprop market. AVCO in the 1970-75 period built exclusively turboshaft, turboprop engines. Garrett specializes in small turbojet and turboshaft engines only, while Teledyne builds only turbojet engines in the small range. Williams Research builds only very small turbojet engines.

Concentration in the Turbine Engine Industry

The turbine engine industry is one of the more highly concentrated of U. S. industries.

Table 2. 5

Percentage Concentration Of
Four Largest Manufacturers
In Value Of Shipments

	1963	1967	1972
SIC 37241 (Aircraft Engines for Military Customers)	96	94	97
SIC 37242 (Aircraft Engines for Other than U. S. Customers)	N/A	N/A	92
SIC 37211 (Complete Aircraft, Military Type)	68	77	74
SIC 37111 (Passenger Cars)	99	99	99

Source: Concentration Ratios in Manufacturing 1972 Census of Manufacturing Bureau of the Census, MC72 (SR) -2.

Table 2. 5 shows that around 95 percent of output in the aircraft engine industry comes from four manufacturers. It is only slightly less concentrated than the U. S. passenger car industry and much more concentrated than the military airframe industry.

Tables 2. 6 and 2.7 show the military engine sales of the top 25 contractors[1/] for DoD procurement category A-1B for 1966 and 1975. The category includes direct engine procurement as well as engine parts.

[1/] Appendix E provides data on a larger number of companies for this procurement category.

Thus, several engine industry subcontractors appear on the list. The concentration of sales dollars in the category is given in the right hand column.

Table 2.8 provides a summary of this information for the top 10 contractors in the years 1966 and 1975. The data shows that in 1966, Pratt and Whitney had 37.7 percent of all procurement dollars in this category, followed by General Electric with 29.7 percent. The top four firms had 90 percent of total engine procurement dollars in 1966. In 1975, concentration in this procurement category had increased significantly. Pratt and Witney significantly increased its dominance from 1966 and accounted for 52.7 percent of engine procurement dollars, although in constant dollars suffered a 34 percent decrease in the 10 year period. General Electric had almost the same market share in 1975 as in 1966, while experiencing a 105 percent sales decrease when measured in constant dollars. AVCO's market share dropped from 14.1 to 2.0 with a corresponding 1223 percent sales decrease in constant dollars. Allison actually increased its market share from 7.7 to 11.0 while experiencing a 32 percent sales drop. Results of the expenditure decline was to increase the concentration in the industry and substantially increase the dominance of Pratt Whitney in the military market. All of the largest 6 turbine engine manufacturers experienced substantial declines in this period, although none exited from the market. Industry adjustment to such a drop in military demand usually takes the form of product diversification or diversification to civilian engine sales,

TABLE 2.6

Military Engine Sales of Top 25 Engine Companies (10-C Code A-1B) for 1966

RANK		SALES ($000)[1]	CUMULATIVE[2] PERCENTAGE
1	United Aircraft Corp.	1,414,516	37.7%
2	GE	1,115,756	67.4%
3	Avco Corp.	528,502	81.5%
4	GM Corp.	287,765	89.2%
5	Curtiss Wright Corp.	123,738	92.5%
6	Canadian Commercial Corp.	45,036	93.7%
7	Continental Aviation and Engineering Co.	36,217	94.6%
8	Garrett Corp.	30,179	95.4%
9	Bendix Corp.	21,952	96.0%
10	Chandler Evans Corp.	19,590	96.5%
11	Boeing Co.	15,500	97.0%
12	International Harvester Co.	9,192	97.2%
13	Marquardt Corp.	7,604	97.4%
14	Sunstrand Corp.	7,423	97.6%
15	Kaman Aircraft Corp.	4,767	97.7%
16	Continental Motors Corp.	3,762	97.8%
17	Holley Carguretor Co.	3,701	97.9%
18	N. American Aviation Inc.	3,238	98.0%
19	Champion Spark Plug Co.	2,281	98.1%
20	Borg Warner Corp.	2,222	98.1%
21	Woodward Governor Co.	2,022	98.2%
22	Airmotive Engineering Corp.	1,986	98.2%
23	Thiokol Chemical Corp.	1,984	98.3%
24	Texas Instruments	1,781	98.3%
25	Lear Siegler	1,711	98.4%
	Base Total for Procurement Area A-1B for 1966	3,752,989	

[1] 1975 constant dollars

[2] Cumulative percent of Total for A-1B Procurement and R&D spending

Source of Data: DoD procurement data base.

TABLE 2.7

Military Engine Sales of Top 25 Engine Companies (10-C Code A-1B) for 1975

RANK		SALES ($000) 1/	CUMULATIVE PERCENTAGE 2/
1	United Technologies Corp.	1,055,688	52.7%
2	General Electric Co.	544,351	79.9%
3	General Motors Corp.	218,956	90.9%
4	Avco Corp.	40,332	92.9%
5	Rolls Royce Ltd.	17,010	93.7%
6	Garrett Corp.	12,397	94.4%
7	Teledyne CAE	12,157	95.0%
8	Bendix Corp.	11,243	95.5%
9	Williams Research Corp.	10,449	96.0%
10	Curtiss Wright Corp.	7,861	96.4%
11	Sunstrand Corp.	7,241	96.8%
12	United Aircraft of West Virginia	4,991	97.0%
13	Canadian Commercial Corp.	4,317	97.3%
14	Lockheed Aircraft Corp.	3,615	97.4%
15	Teledyne Inc,	3,178	97.6%
16	Chandler Evans Corp.	2,504	97.7%
17	Wilson Machine Co. Inc.	1,890	97.8%
18	Gary Aircraft Corp.	1,838	97.9%
19	Alamo Aircraft Supply Inc.	1,673	98.0%
20	Teledyne Industries Inc.	1,637	98.1%
21	Airmotive Engineering Corp.	1,531	98.2%
22	Colt Industries Inc.	1,376	98.2%
23	Aircraft Supplies	1,192	98.3%
24	Lucas Aerospace Std.	1,020	98.3%
25	TRW Inc.	942	98.4%
	Base Total for Procurement Area A-1B for 1975	2,001,834	

1/ 1975 Constant Dollars

2/ Cumulative percent of Total for A-1B Procurement and R&D spending

Source of Data: DoD procurement data base.

TABLE 2.8

Comparison of Concentration for Engine Industry
1966-1975

	1966 Sales[2] ($ Mil)	1966 Rank	1966 Market Share (%)	1975 Sales[2] ($Mil)	1975 Rank	1975 Market Share (%)	% Change
Pratt & Whitney	1414	1	37.7	1055	1	52.7	34
General Electric	1116	2	29.7	544	2	27.2	105
Avco	529	3	14.1	40	4	2.0	1223
Detroit Diesel	289	4	7.7	219	3	11.0	32
Curtiss-Wright	124	5	3.3	8	10	.4	1450
Canadian Commercial	45	6	1.2	4	13	.3	1025
Teledyne CAE[1]	36	7	1.1	12[1]	7	.6	200
Garrett	30	8	.8	12	6	.7	150
Bendix	22	9	.6	11	8	.5	100
Chandler Evans	20	10	.5	3	16	.1	567
Rolls Royce	-	-	-	17	5	.7	-
Williams Research	-	-	-	10	9	.5	-
Total for Procurement Area A-1B	$3753					$2001	

1- Continental

2- 1975 constant dollars

Source of Data: Form 10-C Procurement Data Base.

merger, or decline of the size of each firm or the number of firms.

Diversification of manufacturing capacity to other products by aircraft engine manufacturer has not taken place to any large extent. Three main areas of diversification are marine engines, industrial turbojets and truck diesel engines. Marine and industrial turbojet engine still constitute a very small percentage (less than 3 percent) of industry production. Detroit Diesel has diversified to the manufacture of truck diesel engines.

However, aircraft engine manufacturing operations have followed the general trend toward merger in U.S. industry and many manufacturers have become part of a much more diverse corporate structure in the 1966-1976 period. This has happened through merger with other companies not in the aircraft industry (Pratt Whitney, Teledyne CAE) and through further diversification of engine companies (AVCO, GARRETT). The net result is that aircraft engine operations are embedded within larger companies and generally constitute only a small portion of overall company sales.

It is interesting to note in Table 2.8 that Williams Research in 1975 ranked ninth in DoD engine sales and Rolls Royce ranks fifth. Williams has emerged as the technological leader in very small turbine engines and represents the only new contractor in the 1966-1975 time period.

Rolls Royce is the only foreign engine supplier with a significant DOD sales level. Rolls Royce sales exceeded that of Garrett and Teledyne in 1975.

To compare whether the trend to greater concentration in military engine sales is typical of DOD procurement policies generally, a concentration analysis was undertaken for 13 DOD procurement categories. Concentration ratios for sales within each category were calculated based on military sales data provided for the top 25 firms in each area. The results are given in Tables 2.9 and 2.10 and Figure 2.3. Table 2.9 shows percentage concentration within each procurement category at the 4, 8 and 20 firm level. Figure 2.3 shows that the concentration ratios range widely across procurement categories. The data shows that the aircraft engine area is the most highly concentrated industry for DOD sales when compared to the other procurement areas. Table 2.10 compares direct concentration at the 4 firm level for 1966 and 1975 for the 13 procurement areas. The results show increases in concentration in 12 of the 13 procurement areas from 1966 to 1975. The trend toward greater concentration of DOD procurement dollars may reflect only the tendency to buy fewer major weapon systems. DOD procurement dollar would then be spread to a smaller number of successful bidders. It could also reflect different procurement policies

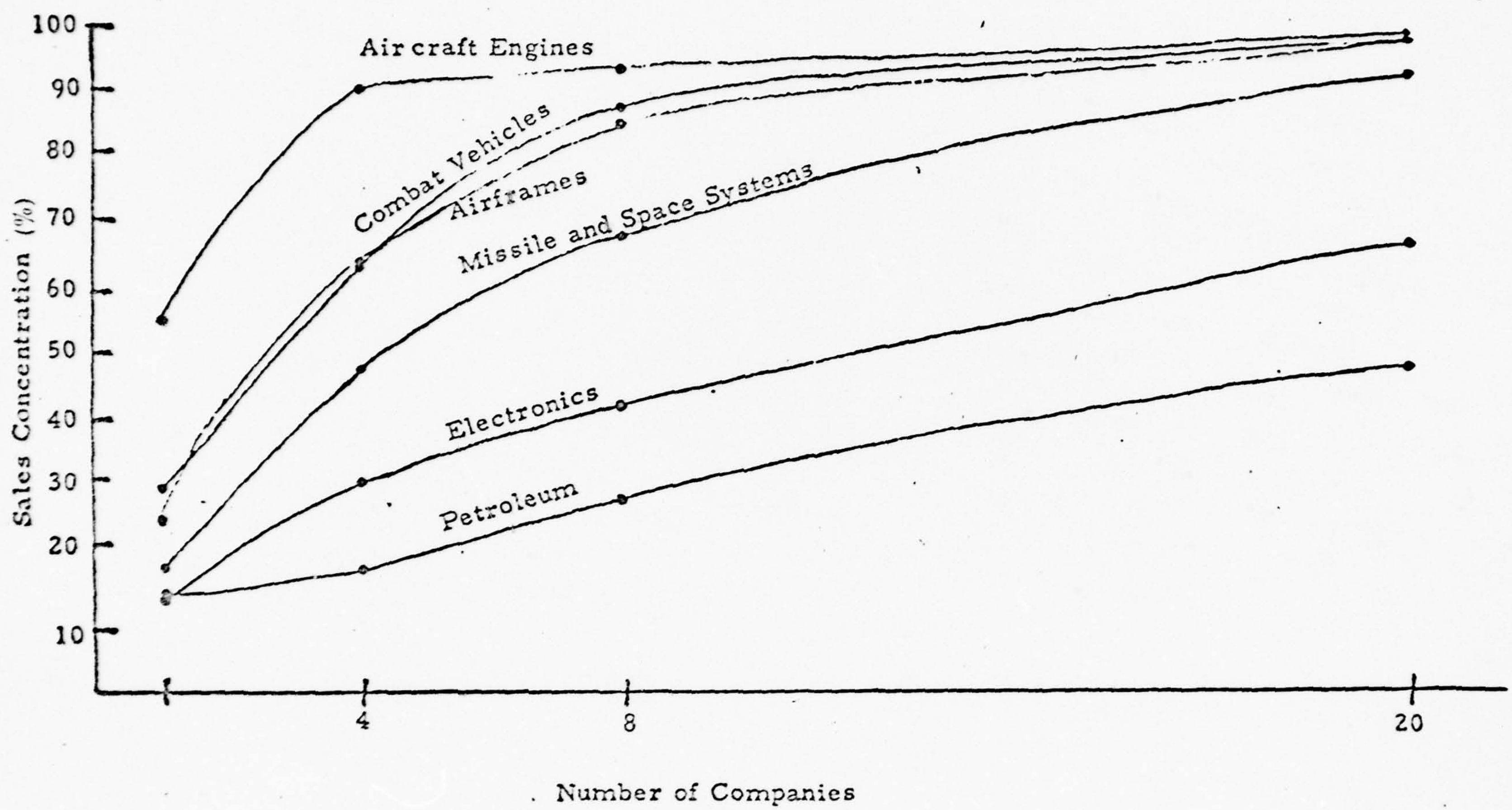
for wartime (1966) and peacetime (1975). The result would seem to be in the long run a greater dependence for the industrial base on a fewer number of firms.

Table 2.9

Comparative Concentration Across 13 DOD Procurement Areas for 1966 and 1975

Number of Firms	1975 4	1975 8	1975 20	1966 4	1966 8	1966 20
		(%)			(%)	
1. Airframes and Related Assemblies and Spares (A-1A)	65	87	99	58	83	99
2. Aircraft Engines and Related Spares and Parts (A-1B)	92	95	100	88	95	99
3. Other Aircraft Equipment and Supplies (A-1C)	33	49	74	25	40	59
4. Missile and Space Systems (A-2)	49	69	94	38	59	87
5. Ships (A-3)	57	81	93	41	58	75
6. Combat Vehicles (A-4A)	65	88	99	67	81	89
7. Non-Combat Vehicles (A-4B)	61	80	96	56	70	82
8. Weapons (A-5)	43	55	73	32	41	55
9. Ammunition (A-6)	31	53	90	21	32	50
10. Electronics and Communications Equipment (A-7)	32	44	68	20	34	57
11. Petroleum (A-8A)	42	62	89	41	64	94
12. Textiles, Clothing and Equipage (A-9)	18	30	50	14	20	32
13. Production Equipment (B-9)	48	60	71	21	35	54

Source of Data: DoD procurement data base.



1975 Concentrations for Seven DOD Procurement Areas

Figure 2.3

Source of Data: Table 2.11 on p. 2-27.

TABLE 2.10

1975 Concentration for DOD Contracts For 13 Procurement Categories

	1975	1966
	Concentration for 4 Firms	
1. Aircraft Engines	92	88
2. Combat Vehicles	65	67
3. Airframes and Related Assemblies	65	58
4. Non- Combat Vehicles	61	56
5. Ships	57	41
6. Missile and Space Systems	49	38
7. Production Equipment	48	21
8. Weapons	43	32
9. Petroleum	42	41
10. Other Aircraft Equipment and Supplies	33	25
11. Electronics and Communication	32	20
12. Ammunition	31	21
13. Textiles, Clothing	18	14

Source of Data: Table 2.10 on p. 2-21.

Military Aircraft Engine Expenditure Data

DOD during the period 1961-1975 has accounted for a declining percentage of total aircraft industry sales. In 1976, DOD probably accounted for approximately 50 percent of sales, whereas at earlier times, it accounted for up to 80 percent of sales. Sales to aircraft engine companies from the government occur primarily in four spending categories as shown in Table 2. 11 and Figure 2. 4. The first category (FSC2840) covers procurement of jet and turbine aircraft engines. DOD procurement expenditure for jet and turbine aircraft engines (FSC2840) are shown in Figure 2. 5. Since 1966, DOD procurement expenditures for jet and turbine engines have declined by almost 50 percent measured in constant dollars. Figure 2. 6 shows RDT&E expenditures for aircraft engines. These expenditures have also declined, although not as severely as engine procurement expenditures. External funds for engine maintenance and modification peaked during the 1968 Vietnam War years and have since declined substantially.

Table 2.11

DOD EXPENDITURES FOR AIRCRAFT ENGINES IN FOUR CATEGORIES

(Millions of 1975 Constant Dollars)

YEAR	FSC2840 [1]	ENGINE RDT&E FUNDS	J502 [3]	K532 [4]	TOTAL
1966	2,969	409	98	15	3,491
1967	2,657	401	150	27	3,235
1968	2,847	519	172	89	3,627
1969	2,388	323	120	24	2,855
1970	1,527	270	160	21	1,978
1971	1,302	317	104	27	1,750
1972	1,315	542	85	39	1,981
1973	1,172	311	77	43	1,603
1974	1,582	261	63	10	1,916
1975	1,515	323	43	10	1,891

1 - Procurement of Jet and Turbine aircraft engines

3 - Engine Maintenance

4 - Engine Modification

Source of Data: DoD procurement data base.

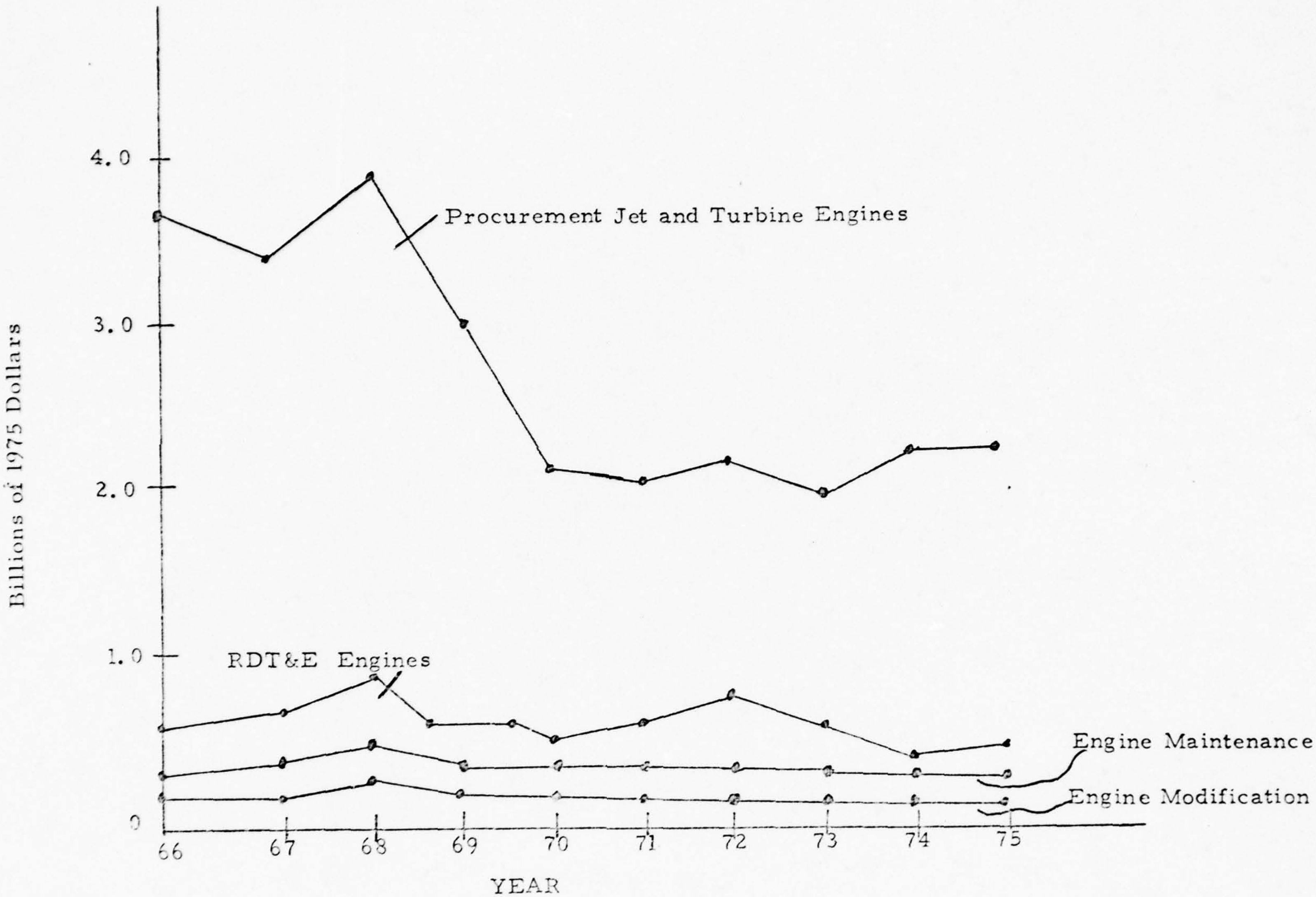
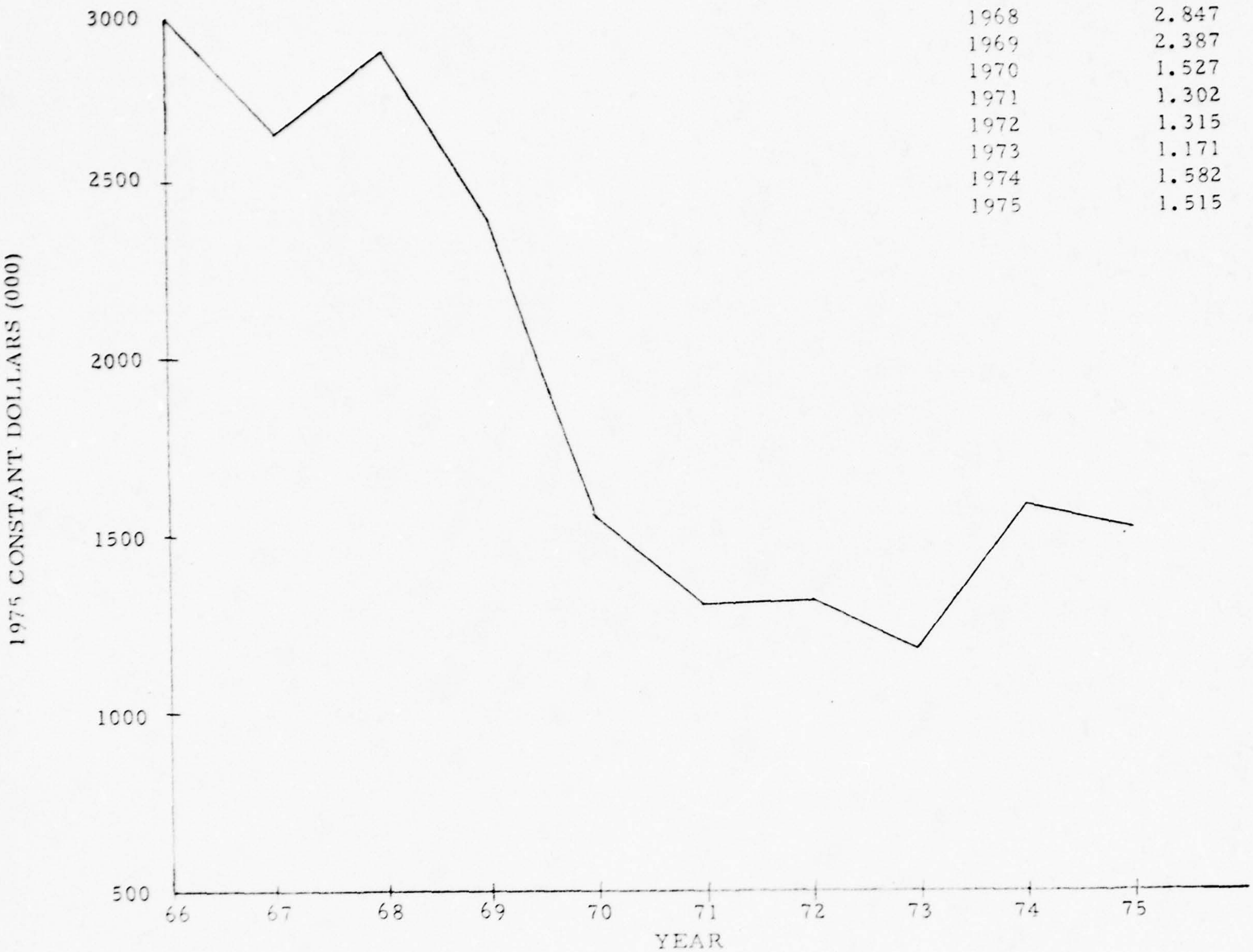


Figure 2.4 DOD Expenditures for Aircraft Engines in Four Categories

Source of Data: Table 2.11.

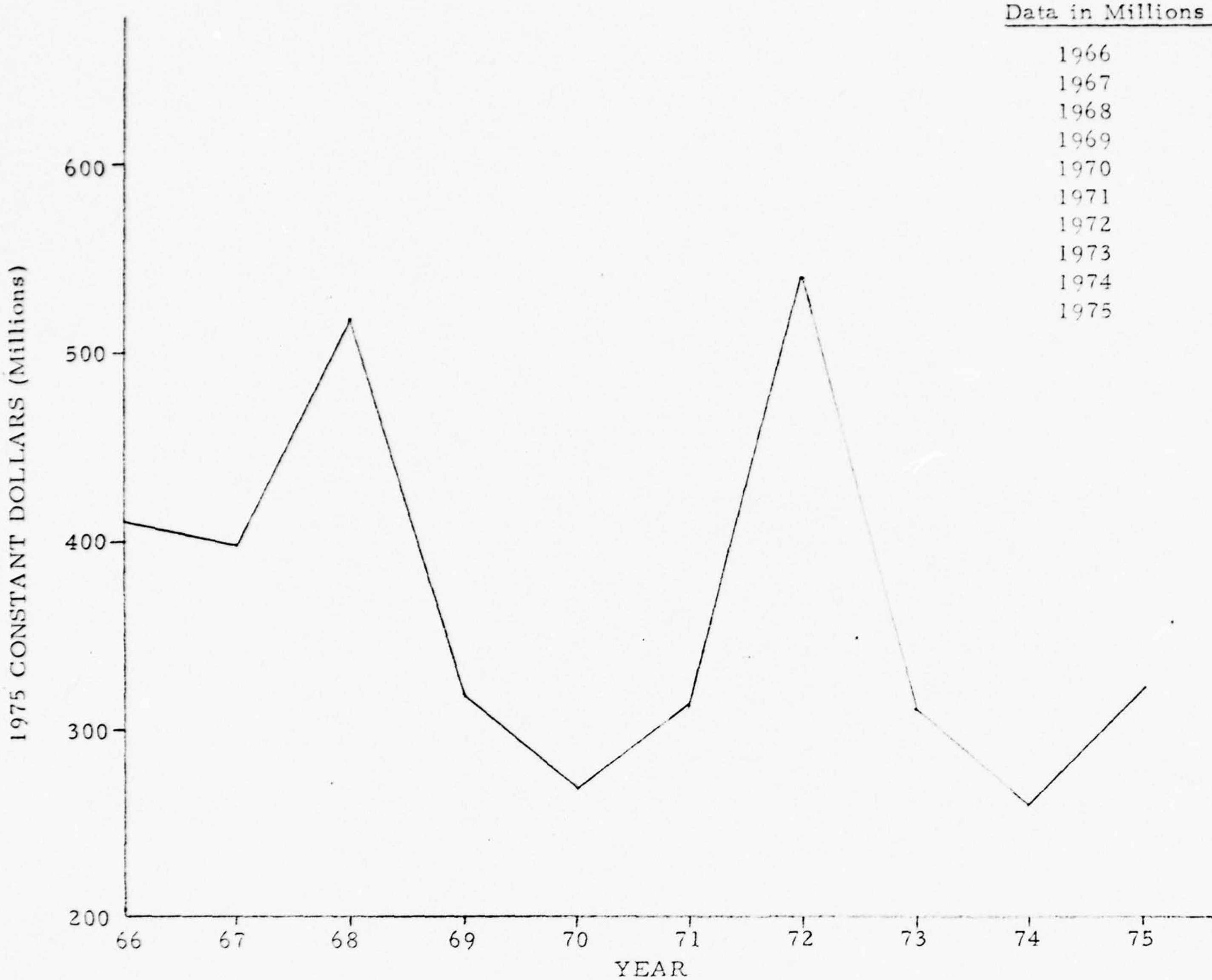


Data in Billions of 1975 Dollars

1966	2.969
1967	2.657
1968	2.847
1969	2.387
1970	1.527
1971	1.302
1972	1.315
1973	1.171
1974	1.582
1975	1.515

Figure 2.5 DoD Expenditures in FSC 2840 (Gas Turbines, Jet Engines for Aircraft)

Source of Data: Table 2.11.



Data in Millions of 1975 Dollars

1966	410
1967	401
1968	519
1969	324
1970	270
1971	317
1972	542
1973	312
1974	261
1975	323

Figure 2.6 RDT&E Expenditures for Aircraft Engines

Source of Data: Table 2.11.

Historical Turbine Engine Production

Historical turbine engine production can be measured in several ways:

1) Dollar volume of turbine engine sales
2) Number of engines produced
3) Total weight of engines produced
4) Total pounds of thrust produced.

For the seven turbine companies in question, dollar volume data was not provided in all cases. However, production data corresponding to number of engines produced, total weight and total thrust have been developed from the data provided. See Table 2.12. Each of the measures used for total industry production capacity has deficiencies. The measure of number of engines produced equally weighs very small and very large engines. If the mix of very small or very large engines changes over time, their measure will not track actual production capacity accurately. The measure of weight of engines produced solves this problem but fails to track the trend to use of lighter materials and greater thrust to weight ratios in engines. The measure of pounds of thrust is perhaps theoretically the best measure since it is a performance measure. Unfortunately, measurement of pounds of thrust may not be uniform between engine types. For instance, turboshaft engines are usually rated in horsepower rather than pounds of thrust, and con-

version factors are only accurate under a single test operating condition.[1/] Figure 2.17 compares the three measures estimated. The correlation coefficients are shown in Table 2.13. Since the correlation coefficient is very high between the measures, no significant bias will be introduced by using any one measure as a measure of production.

The production data shows three distinct periods. The period 1961-1965 shows relatively stable production. The peak production period was for 1966-1970. The peak corresponds with the Vietnam war and peak civilian aircraft demand. During the period 1971-1975, demand has dropped well below 1961-1970 levels by all three measures. Table 2.14 compares total production during the three-5-year periods. Levels of production in 1971-1975 have fallen roughly 25 percent when compared to 1961-1965 and 55 percent when compared to 1966-1970 levels. Production in 1975 was roughly 38 percent of peak production in the 1961-1975 period.

Table 2.15 breaks the production data between the two major engine classes. Table 2.16 summarizes this production data again in terms of the three time periods. Production of turboshaft, turboprop engines has fallen more drastically than turbo jet, turbofan engines. Comparing 1975 levels to peak years, turboshaft, turboprop engines are 26 percent of peak years, while turbojet, turbofan are 46 percent of peak years in 1975.

[1/] For calculating total pounds of thrust, a conversion factor of 1.6 pounds of thrust/horsepower was used.

Table 2.17 shows the size of the different turbine engine submarkets based on total number and total weight of engines produced from 1961-1975. In terms of number of engines, the largest market was for turbojet, turbofan engines in the 6-18 thousand pounds of thrust range, with 35,000 engines, followed by the 1-6 thousand pounds of thrust with 22,000 engines. In terms of weight (more closely correlated with sales), the market is dominated by two classes--turbojet, turbofan in the 6-18 and 18-55 thousand pounds of thrust. These two classes account for over 80 percent of the production by weight.

1/ For calculating total pounds of thrust, a conversion factor of 1.6 pounds of thrust/horsepower was used.

Table 2.12

Turbine Engine Production Data[1/] (1961-1975)

Year	Number of Engines	Lbs. of Engines (10^6)	Lbs. of Thrust (10^6)
1961	5772	14.4	56.8
1962	5780	14.0	53.0
1963	5742	12.8	48.9
1964	6362	13.3	56.6
1965	6962	13.4	59.9
1966	9996	18.1	81.2
1967	12798	25.2	111.4
1968	13797	23.3	101.9
1969	10321	19.0	85.6
1970	7791	18.0	83.3
1971	4711	12.7	55.9
1972	3235	8.7	34.1
1973	4164	9.6	39.8
1974	4744	10.0	41.8
1975	5189	9.7	43.5
Average	7160	14.81	63.6
Standard Deviation	3170	4.97	23.5

1/ Source of Data: MATHTECH Survey.

Figure 2.7 - TURBINE ENGINE PRODUCTION (1961-1975)

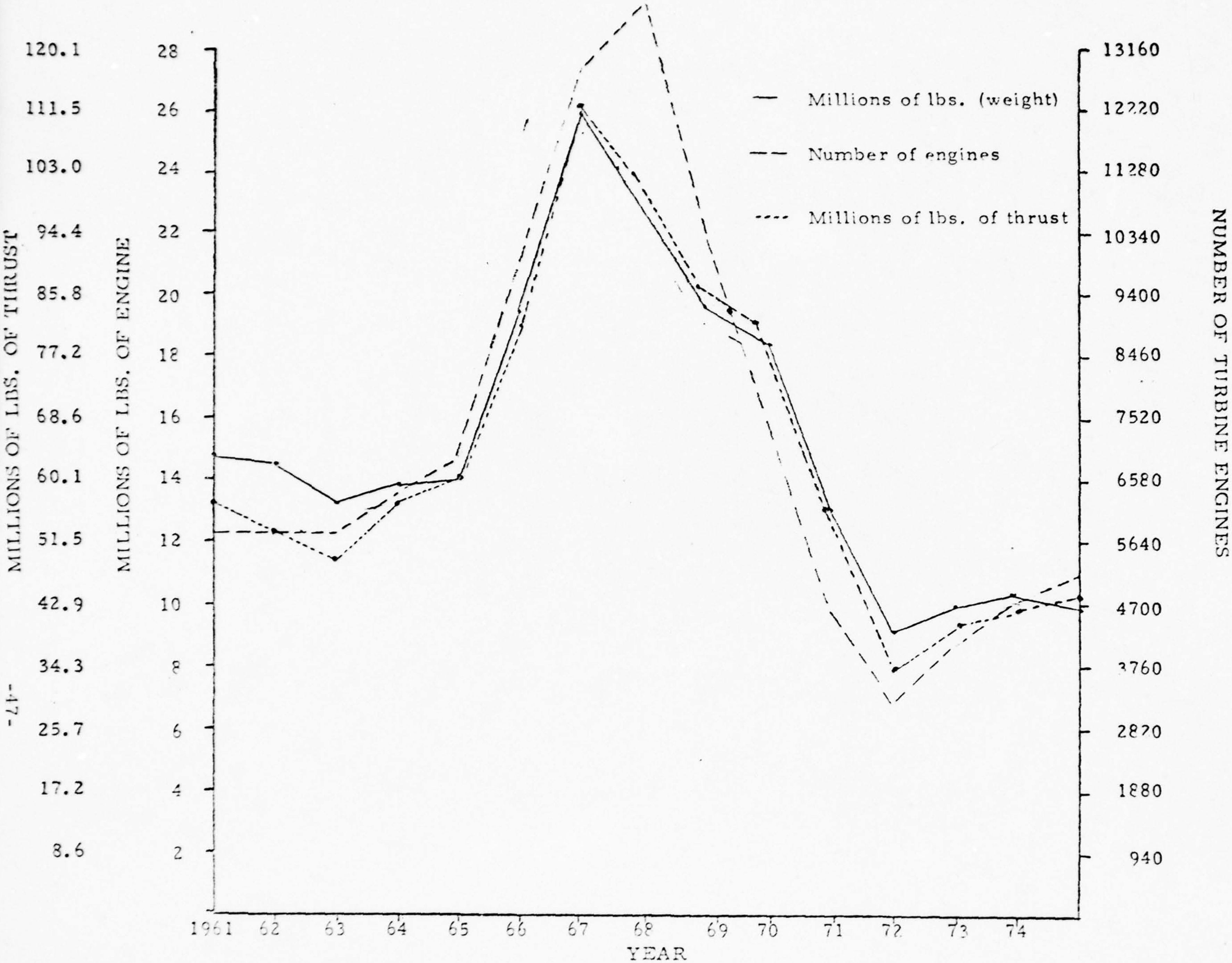


Table 2.13

Correlation Coefficients Between Measures of Turbine Engine Production

		(1)	(2)	(3)
Number of engines	(1)	1.0	.96	.96
Pounds of engine	(2)	.96	1.0	.99
Pounds of thrust	(3)	.96	.99	1.0

Source of Data: Table 2.12 on p. 2-32.

Table 2.14

Comparison of Turbine Engine Production Measures for Three Time Periods

	1961-65	1966-70	1971-75
Number of engines	30580	54700	22040
Pounds of engines - 10^6	68	104	51
Pounds of thrust - 10^6	275	463	215

Source of Data: Table 2.12 on p. 2-33.

Table 2.15

Engine Production (No. of Engines) For Two Engine Types

	Turbojet/Turbo Fan	Turboshaft/Turbo Prop
1961	4490	1282
1962	4075	1705
1963	3465	2277
1964	3836	2490
1965	4039	2923
1966	5708	4288
1967	7309	5489
1968	7099	6698
1969	5932	4389
1970	5192	2599
1971	3194	1517
1972	2419	816
1973	2745	1419
1974	3172	1572
1975	3428	1761

Source of Data: MATHTECH Survey.

Table 2.16

Comparison of Production Data for Three Time Periods

	1961-65	1966-70	1971-75
Turbojet - Turbo fan			
Number of engines	19905	31240	14958
Turboshaft - Turbo prop			
Number of engines	10677	23463	7085

Table 2.17

MARKET SIZE

	Number of Engines 1961-75	Percentage	Weight[1/]	Percentage	Number of Companies
Turbojet, Turbofan					
0 - 1	3,500	3	1	—	2
1 - 6	22,000	20	5	2	4
6 - 18	35,000	32	140	63	3
18 - 55	6,900	6	40	18	2
Turboshaft, Turboprop					
0 - 2,000	29,000	27	15	7	4
>2,000	12,000	11	20	9	4
TOTAL	108,400		221		

1/ Millions of Lbs. of Engine

Lead Times for Turbine Engine Components

The long lead times for turbine engine production is primarily due to the lead time required to obtain certain component parts. Actual in-house production time for engines is only approximately 20 per cent of total lead time.[1/] Table 2.18 shows longest and shortest lead time experienced for different component parts during the 1961-75 period. Controls and bearings have the longest lead time taking approximately 13 and 10 months from order time. Figure 2.8 shows the trend in lead times experienced by manufacturers from 1963-75. During this period lead times have changed significantly. For instance lead time for controls has been as low as 11 months and as high as 15 months. Current lead times are well above the lead times experienced in the early 60's for controls and bearings. The trend to longer lead time could be caused by several factors:

- More complex components
- Changes in capacity and capacity utilization in subcontractor industries
- Wartime vs. peacetime priority
- Longer raw material lead times

Further investigation of the reason for lead time variance seems warranted since these lead times are often on the critical path in engine production. Reduction in total engine lead times of up to 25 per cent may be possible if lead times experienced during a defense surge were equal to the shortest historical experience rather than the longest.

1/ According to MATHTECH survey data.

Based on the limited data available, prestocking of certain control items also looks to be a policy worth investigating in reducing surge lead times. Prestocking of either certain raw material or end products such as controls and bearings might lead to significant reductions in surge lead times.

Table 2.18

Lead Time Data in Months for Turbine Engine Parts (1962-1975)

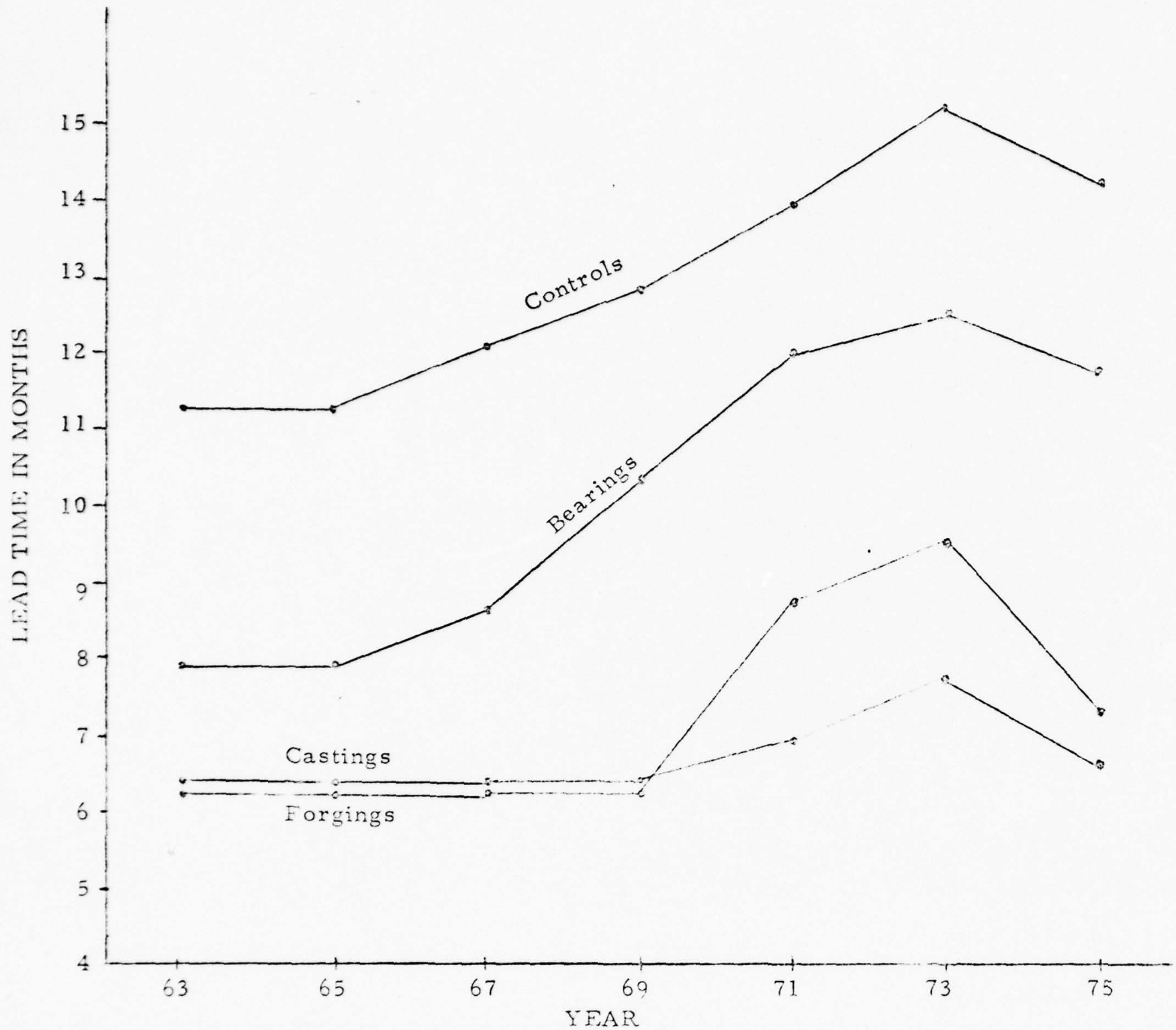
	Company [1/] Averages for Shortest Lead Times	Company [1/] Averages for Longest Lead Times	Averages of Company [2/] Means
Castings	6.3	7.9	6.8 ± 1
Forgings	6.3	10.0	8.2 ± 2
Controls	11.3	15.2	13.4 ± 2
Fabricated and Machined Parts	7.0	9.2	9.1 ± 1
Gears and Gearboxes	5.6	8.0	8.1 ± 1
Bearings	7.9	12.7	10.7 ± 2

Source of Data: MATHTECH survey data.

1/ Data available from 3 companies on longest and shortest lead times

2/ Data available from 4 companies on average lead times.

Figure 2.8 - Lead Time Trends for Selected Turbine Engine Parts (1963-1975)



Source of Data: Table 2.17.

Table 2.19 shows data on total engine lead time for engines currently in production. Companies were asked to provide the longest and shortest lead time experienced for each engine. The average turbine engine currently in production has an average longest and shortest lead time of 16.7 and 14.4 months respectively, and engine lead times can range from 10 to 21 months. Engine lead time seems to vary weakly with engine size, and by manufacturer.

Table 2.19

Lead Time Characteristics for Current Engines in Production

	Longest Lead Time (Months)	Shortest Lead Time (Months)
Average	16.7	14.4
Standard Deviation	2.8	3.4
Range	12-21	10-21

Production and Employment in the Turbine Engine Industry

Data was available from 6 companies on employment in the 1961-1975 time period. Employment Data gathered broke out production workers from engineering and managerial staff. The relationship between each of these employment categories and productionas measured in lbs. of engine was explored. For production workers, the number of workers was assumed to be a simple linear function of production levels

$$N_t = a_0 + a_1 p_t$$

N_t = number of production workers in year t in thousands

p_t = production level in million lbs. of engine in year t

$a_0 a_1$ = regression coefficients

The results of two regressions based on different delays is given in Table 2.20.

Table 2.20

Relationship of Production Workers and Production in Turbine Industry

	Delay (0 years)	Delay (1 year)
a_0	26.1	22.7
a_1	1.41	1.73
standard error a_0	3.6	2.1
standard error a_1	.33	.19
r^2	.59	.87
standard error $\hat{y}$	4.82	2.8

The data shows that a much better fit is obtained with a delay of one year in the production worker variable N_t. The delay probably indicates the time required to train new production workers and bring them to maximum utilization and production. Figure 2.9 compares actual production workers to the predicted number from the regression equation. As can be seen, there is a close relationship between production employment and production.

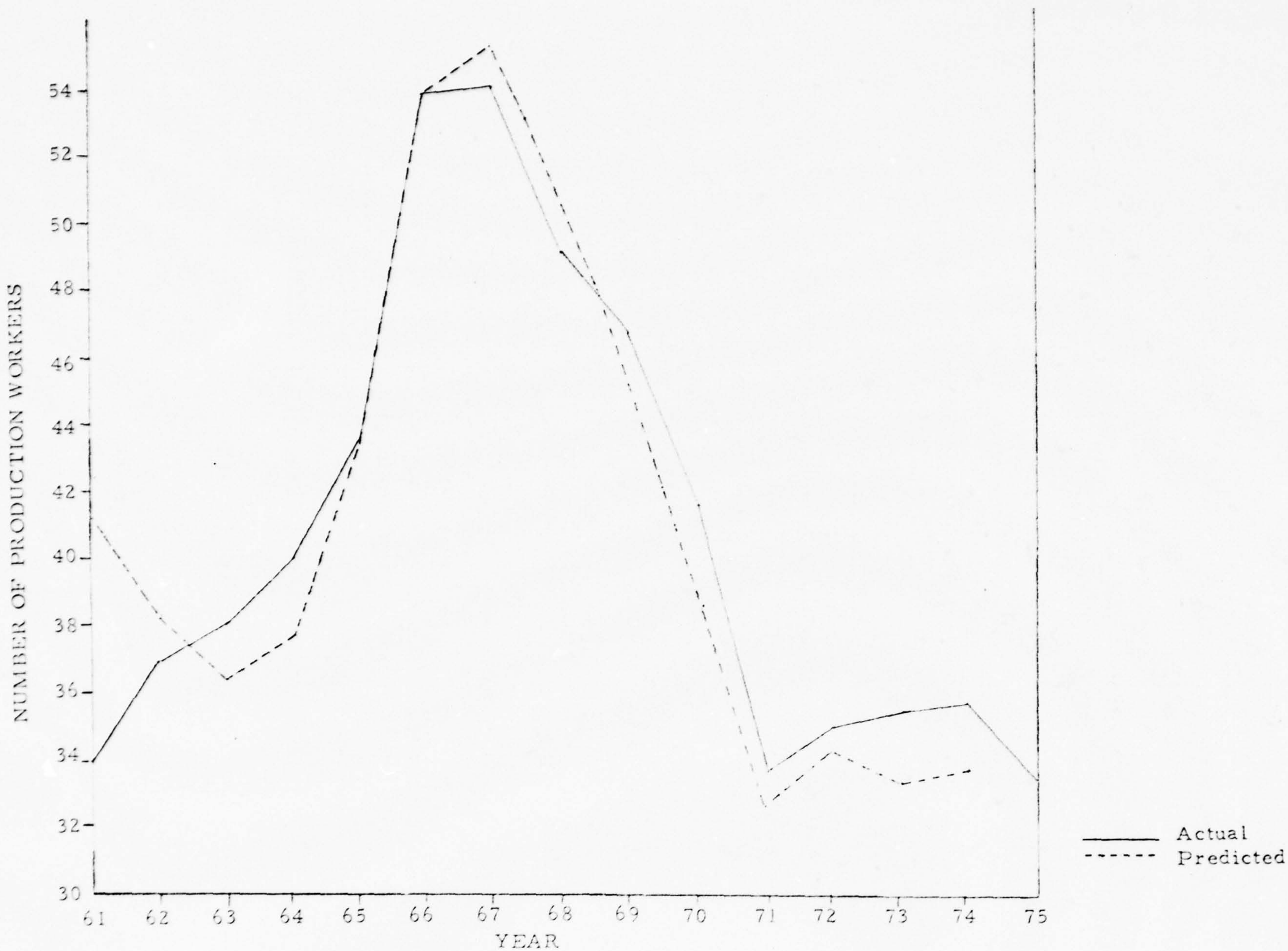


Figure 2.9 - Actual and Predicted Production Workers

Engineering and managerial staff levels would be expected to be less dependent on annual production levels. A similar analysis was undertaken exploring the relationship between production output and engineering and managerial staff.

$$N'_t = a_0 + a_1 p_t$$

N'_t = number of engineering and managerial workers in thousands in year t

p_t = production level in million of lbs. in year t

a_1, a_0 = regression coefficients

Table 2.21

Relationship between Turbine Engine Production and Engineering and Managerial Staff

a_0	13.59
a_1	.44
standard error a_0	2.0
standard error a_1	.18
r^2	.33
standard error y	2.6

Table 2.21 shows the results. Figure 2.10 compares actual engineering staff to that predicted by the regression. The data shows for both groups a significant component of "fixed" employment, i.e. staff at zero levels of output. This can be interpreted as the staff required to maintain a credible capability

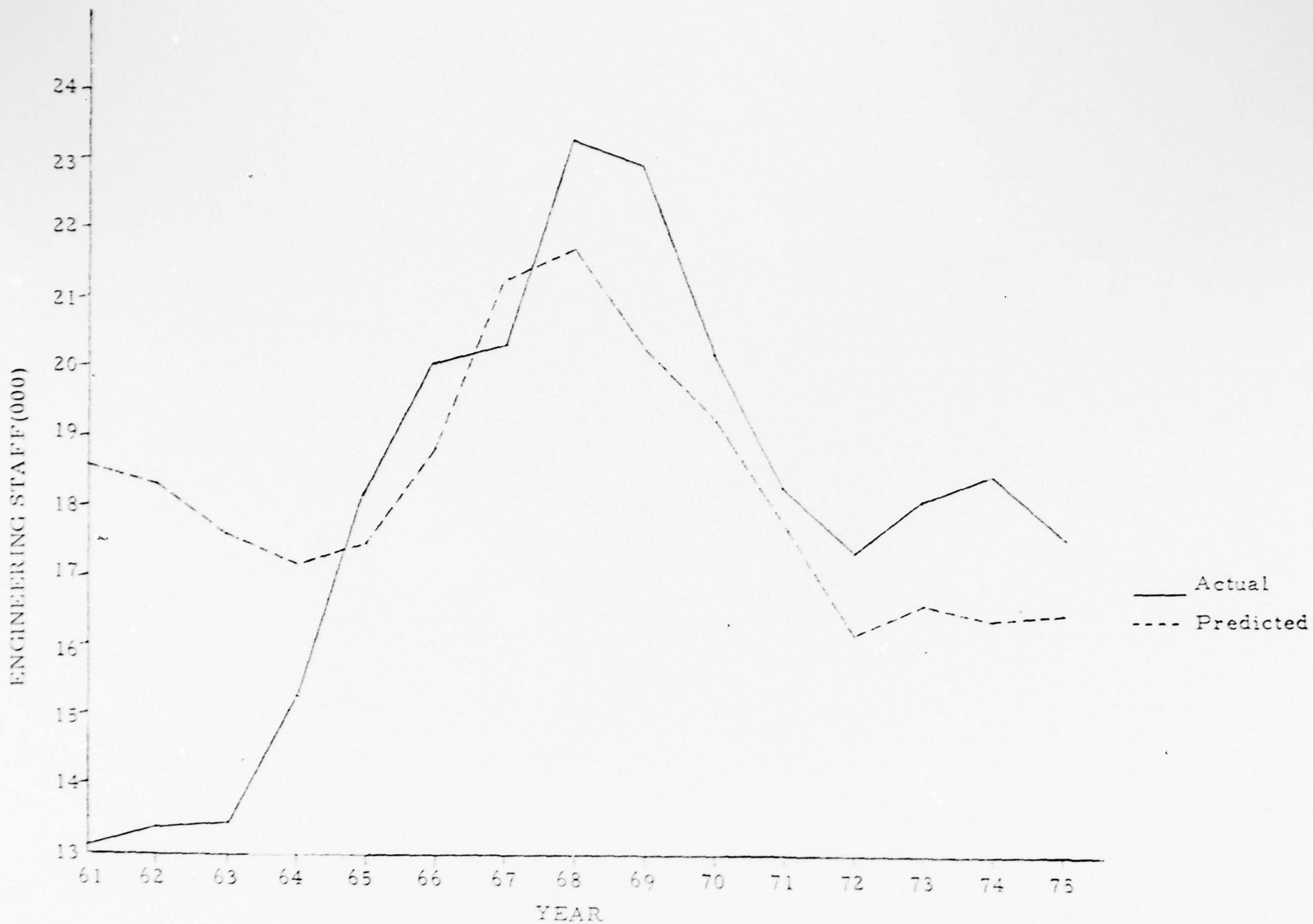


Figure 2.10 - Actual and Predicted Engineering and Managerial Personnel

to produce engines. The component of the staff that is fixed ($a_0/\bar{y}$) is roughly 75 percent for the engineering category and 64 percent for the production category. Figure 2.11 shows the average output per production and engineering worker. Generally, the data shows that higher output per worker levels are associated with high levels of output. In periods of high levels of output utilization of machinery and people tend to be more efficient (overtime, etc.). In periods of lower level of output (1971-1975), the data would suggest less efficient utilization of people and machinery and a tendency to retain key production and engineering staff skills even if utilization is low. This trend might also be due to the larger portion of output subcontracted out during peak production periods. This productivity pattern is the opposite of what would be expected of an industry operating near optimal efficiency. As demand goes up in such an industry, less efficient production resources would have to be brought up, which would lower average productivity. This is also illustrated in Figure 2.9 and Figure 2.10 where in the 1971-1975 period, the actual production staff is greater than that predicted by the regression equation. The overall trend can also partly reflect a tendency to greater engine complexity and sophistication requiring additional labor input.

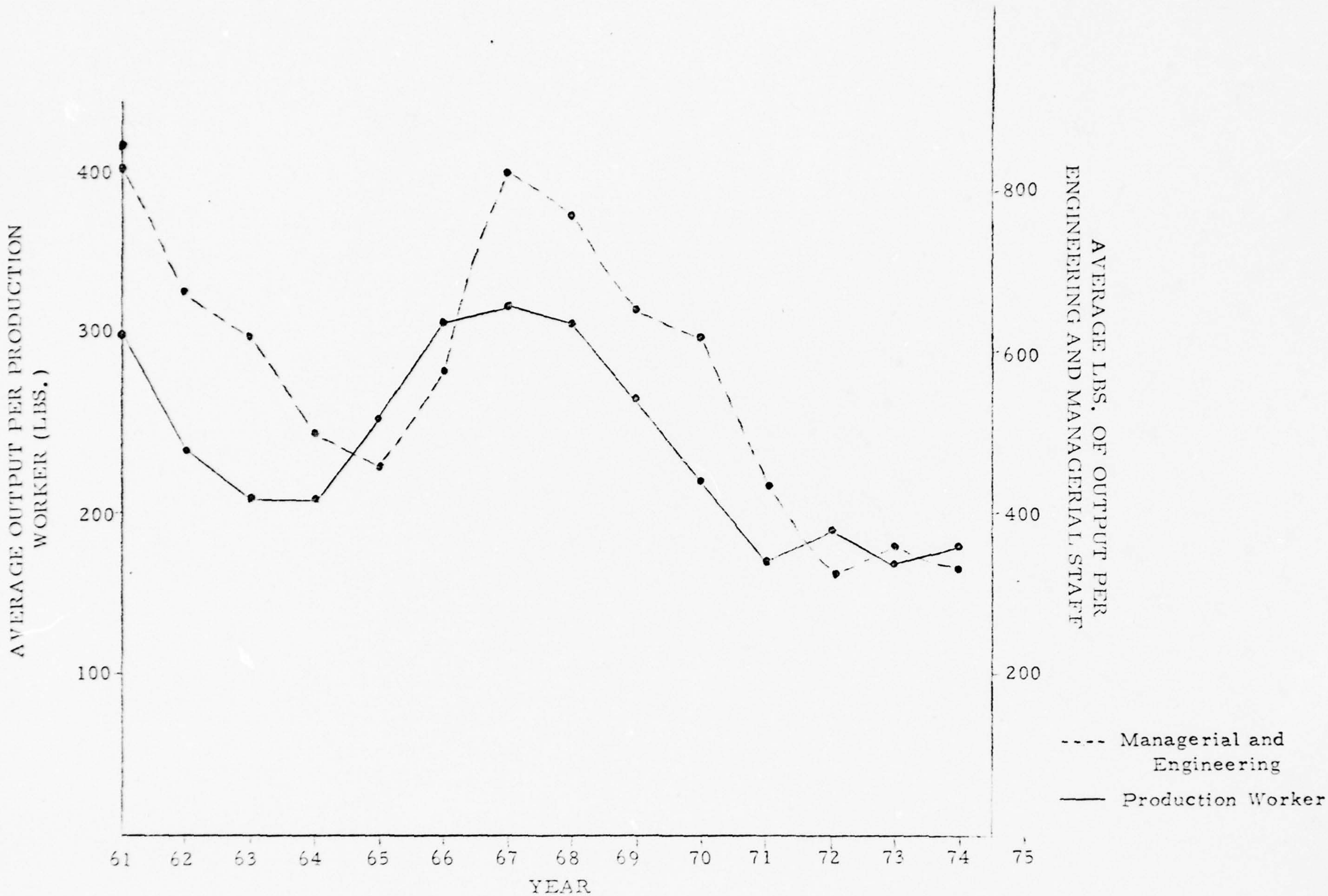


Figure 2.11 - Estimated Average Output per Production Worker in Turbine Engine Industry

Turbine Engine Production and Floor Space

Figure 2.12 shows the relationship between engine production and floor space (company and government owned) over the 1961-75 period for 5 firms. The data shows a period (1966-67) of major expansion of industry floor space coinciding with the production peak. However, the production decline of the 1970's has not yet resulted in any decline of industry floor space. This is probably due to the relatively inexpensive cost of keeping excess floor space when compared to the potential cost of building additional floor space if sales increase. The data does show that there is a considerable excess of floor space currently when compared to production levels of the 1960's.

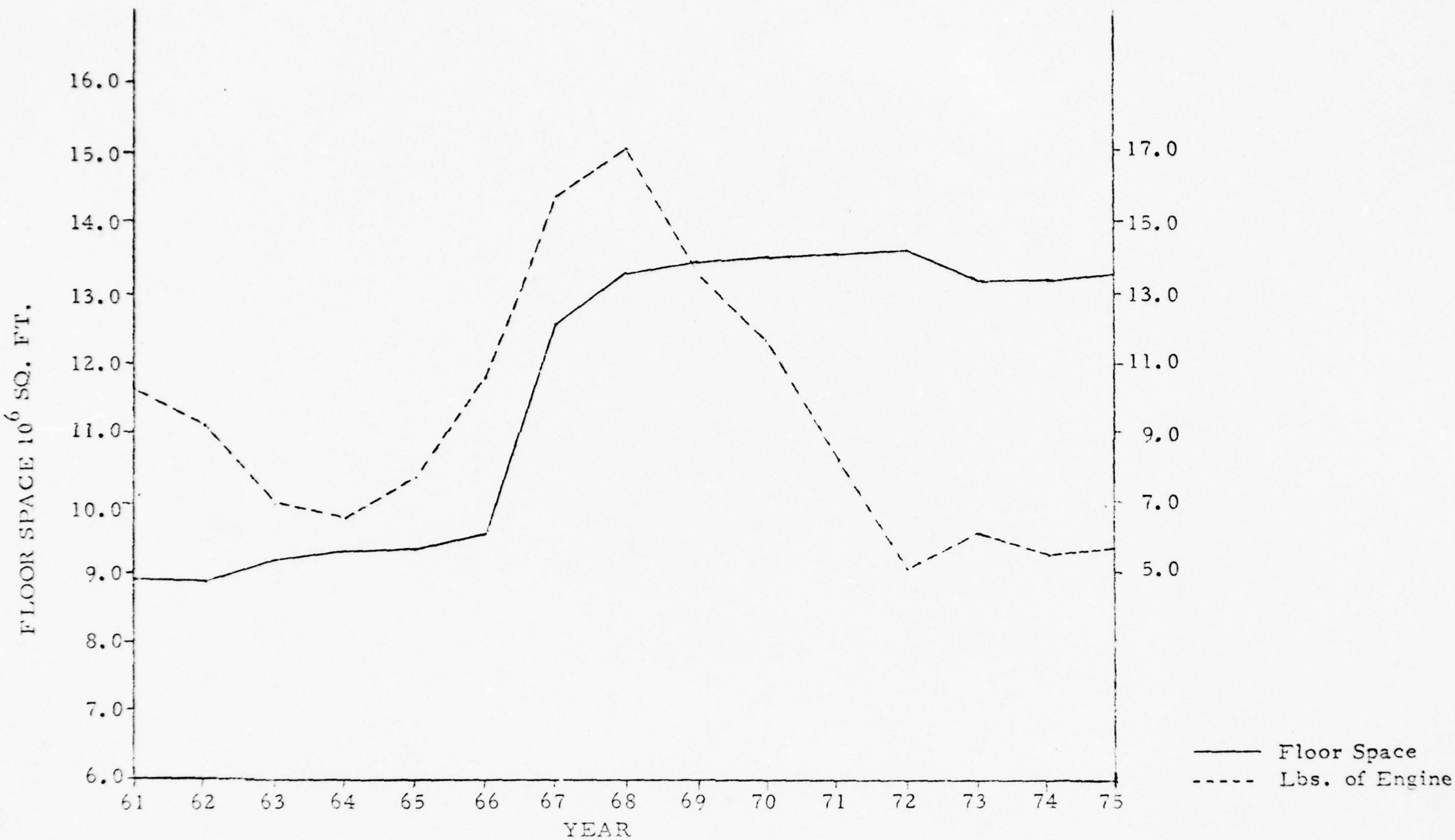


Figure 2. 12- Floor Space and Engine Production for 5 Turbine Engine Manufacturers

Surge Capacity of the Turbine Engine Industry

An economic definition of Surge Capacity is the maximum amount of lbs. of engines that can be produced during a given time with existing plant and equipment in the turbine engine industry. It is assumed in this definition that labor and material inputs are unlimited, and the only constraint on ultimate capacity is the physical plant and equipment. As output is increased, utilization of machinery and plants increase by adding labor, extra shifts and more days per week. At some point, maximum practical capacity with current plant and equipment is reached. Normally turbine manufacturers will operate somewhat below this maximum practical capacity for at least two reasons.

- Under most manufacturing cost conditions, in the face of stochastic demand, capacity will be built exceeding average demand in order to maximize profit. Thus a certain level of surge capacity will exist to take advantage of unexpected demand.
- Profit maximization usually occurs operating below maximum practical capacity since added labor inputs are less productive and more costly.

The turbine engine industry in addition has some peculiar characteristics which make definitions of surge capacity somewhat more difficult than most manufacturing sectors.

In most manufacturing sectors, the time required to adjust plant and equipment capacity is significantly longer than the time required to adjust manufacturing output. Thus production increases can usually occur over a period of months, while capacity increases usually take place over a period of years. Thus production in the short run with current capacity and production in the long run with increased capacity are clearly delineated. However, production increases in the turbine industry occur normally over a period of 1 to 2 years due to the long lead time required for certain engine components. This long lead time makes a precise definition of surge capacity more difficult since adjustment of physical plant and even machinery can occur in time periods only somewhat longer than engine lead time. In the face of estimated strong sustained increased demand, industry adjustment of plant and equipment can occur with lead times only moderately longer than actual increases in production. While production increases can occur in a 1-2 year time frame depending on engine type, capacity adjustments can occur in a 2-3 year time frame. This industry characteristic somewhat diminishes the importance of the concept of maximum practical capacity for defense surge planning in the turbine industry.

Capacity Data gathered in the Survey of Plant Capacity is shown in Tables 2.22, 2.23, 2.24 and 2.25. This data was generated in special tabulations requested from Bureau of the Census. Data on average shifts per day, average days per

Table 2.22-AVERAGE NUMBER OF SHIFTS PER DAY AT ACTUAL PRODUCTION, PREFERRED CAPACITY, AND PRACTICAL CAPACITY FOR SELECTED INDUSTRIES FOR THE FOURTH QUARTER OF 1973, 1974, AND 1975

SIC CODE AND TITLE	FOURTH QUARTER 1973			FOURTH QUARTER 1974			FOURTH QUARTER 1975		
	ACTUAL	PREFERRED	PRACTICAL	ACTUAL	PREFERRED	PRACTICAL	ACTUAL	PREFERRED	PRACTICAL
3721 - Aircraft	1.8	2.2	2.6	1.8	2.3	2.7	1.9	2.1	2.6
3724 - Aircraft engines and engine parts	2.4	2.6	2.9	2.1	2.2	2.5	2.0	2.2	2.5
3728 - Aircraft equipment, n.e.c.	1.9	2.1	2.5	1.9	2.2	2.4	1.9	2.2	2.6

Source: Unpublished Data, Bureau of the Census.

Table 2.23 - AVERAGE NUMBER OF DAYS PER WEEK IN OPERATION AT ACTUAL PRODUCTION, PREFERRED CAPACITY, AND PRACTICAL CAPACITY FOR SELECTED INDUSTRIES FOR THE FOURTH QUARTER OF 1973, 1974, AND 1975

SIC CODE AND TITLE	FOURTH QUARTER 1973			FOURTH QUARTER 1974			FOURTH QUARTER 1975		
	ACTUAL	PREFERRED	PRACTICAL	ACTUAL	PREFERRED	PRACTICAL	ACTUAL	PREFERRED	PRACTICAL
3721 - Aircraft	5.1	5.1	5.3	5.2	5.2	5.6	5.2	5.2	5.5
3724 - Aircraft engines and engine parts	5.3	5.3	5.5	5.2	5.2	5.4	5.2	5.3	5.5
3728 - Aircraft equipment, n.e.c.	5.2	5.2	5.6	5.3	5.2	5.5	5.1	5.0	5.3

Source: Unpublished Data, Bureau of the Census

Table 2.24 - AVERAGE NUMBER OF HOURS PER DAY IN OPERATION AT ACTUAL PRODUCTION, PREFERRED CAPACITY, AND PRACTICAL CAPACITY FOR SELECTED INDUSTRIES FOR THE FOURTH QUARTER OF 1973, 1974, AND 1975

SIC CODE AND TITLE	FOURTH QUARTER 1973			FOURTH QUARTER 1974			FOURTH QUARTER 1975		
	ACTUAL	PREFERRED	PRACTICAL	ACTUAL	PREFERRED	PRACTICAL	ACTUAL	PREFERRED	PRACTICAL
3721 - Aircraft	16.2	18.3	23.5	15.1	18.8	21.9	15.3	17.3	20.5
3724 - Aircraft engines and engine parts	18.9	20.7	22.3	17.0	18.3	20.2	16.7	17.8	19.8
3728 - Aircraft equipment, n.e.c.	17.3	16.9	19.9	15.7	18.1	19.4	14.9	17.2	20.2

Source: Unpublished Data, Bureau of the Census

Table 2.25- ACTUAL OPERATIONS AS A PERCENTAGE OF PREFERRED AND PRACTICAL RATES OF OPERATIONS FOR THE FOURTH QUARTER OF 1973, 1974, AND 1975

SIC CODE AND TITLE	FOURTH QUARTER 1973		FOURTH QUARTER 1974		FOURTH QUARTER 1975		STANDARD ERROR OF ESTIMATE (PERCENT) 1975 PRACTICAL
	PREFERRED	PRACTICAL	PREFERRED	PRACTICAL	PREFERRED	PRACTICAL	
3721 - Aircraft	63.3	60.3	67.9	61.0	68.6	59.1	1
3724 - Aircraft engines and engine parts	78.0	71.7	[illegible]	67.6	78.1	68.4	2
3728 - Aircraft equipment, n.e.c.	74.0	68.0	[illegible]	62.5	67.6	60.2	4
372 - Aircraft and Parts	NA	NA	73.0	63.0	68.0	60.0	1
37 - Transportation Equipment	NA	81.0	76.0	71.0	77.0	72.0	2
- Durable Goods	NA	84.0	80.0	75.0	77.0	71.0	4

Source: "Survey of Plant Capacity," Bureau of the Census

UNPUBLISHED DATA
Source: Bureau of the Census
Department of Commerce
Washington, D.C. 20233

week, number of hours per day is given for actual, preferred and maximum practical capacity levels. Comparison is made among companies in SIC 3721 (Aircraft), 3724 (Aircraft Engine and Engine Parts), and 3728 (Aircraft Equipment). The data shows that the aircraft engine industry at maximum capacity could operate with 2.5-2.9 shifts per day, 5.4-5.5 days per week and 20-22 hours per day. Currently the industry is averaging 2.0 shifts, 5.2 days per week and 16.7 hours per day. Table 2.25 provides the estimated actual present production as a percentage of the preferred and practical rates. The data shows the aircraft engine industry to be operating at an estimated 68-72 per cent of maximum practical capacity. Capacity utilization for the engine industry is significantly higher than for the aircraft (airframe) industry but generally lower than for durable goods. A rough estimate of surge capacities from the Survey of Plant capacity for SIC code 3724 (aircraft engines and engine parts) would be 100/70 = 1.44.

The aircraft turbine industry behaves somewhat differently from the airframe industry in periods of surge. Tables 2.21 - 2.24 show that the turbine industry's actual and preferred operating mode is to work more shifts per day, more days per week and more hours per day than the airframe industry. This is probably due to the desire to maintain high machine utilization. However, the hours of operation at maximum practical capacity is less than the airframe industry. This is probably due to the need for machine maintenance and repair. The added production from adding hours of operation will not be as great in the turbine industry as the airframe industry.

In the 1966-1968 surge, a change in working behavior was an addition to a third shift. From MATHTECH data, third shifts in periods of surge become 15-25 percent of the workforce as compared to 5-15 percent during nonsurge periods. Second shift does not change as drastically since second shifts are common even in periods of low production.

The second major change in periods of surge is shifts in the make/buy ratio. Typically, 50 to 55 percent of engine costs will be to outside sources. In periods of surge this make/buy rate can decline to 30/70. Thus a significant component of surge capability for the industry is through outside firms. Characteristics of turbine firms themselves are not, thus, sufficient to determine engine surge capacity. Turbine manufacturers are highly dependent on suppliers and subcontractors in times of surge to also have spare capacity.

Historical Surge Capacity Rates

The high production rates in the aircraft industry in the 1966-1968 period provides an excellent opportunity to study actual industry adjustment to increased production. Table 2.26 and Figure 2.13 shows the maximum rate of expansion in production experienced by each of the engine manufacturers in the 1961-1975 period.

Table 2.26

Historical Maximum Percentage Production Increases[1/]

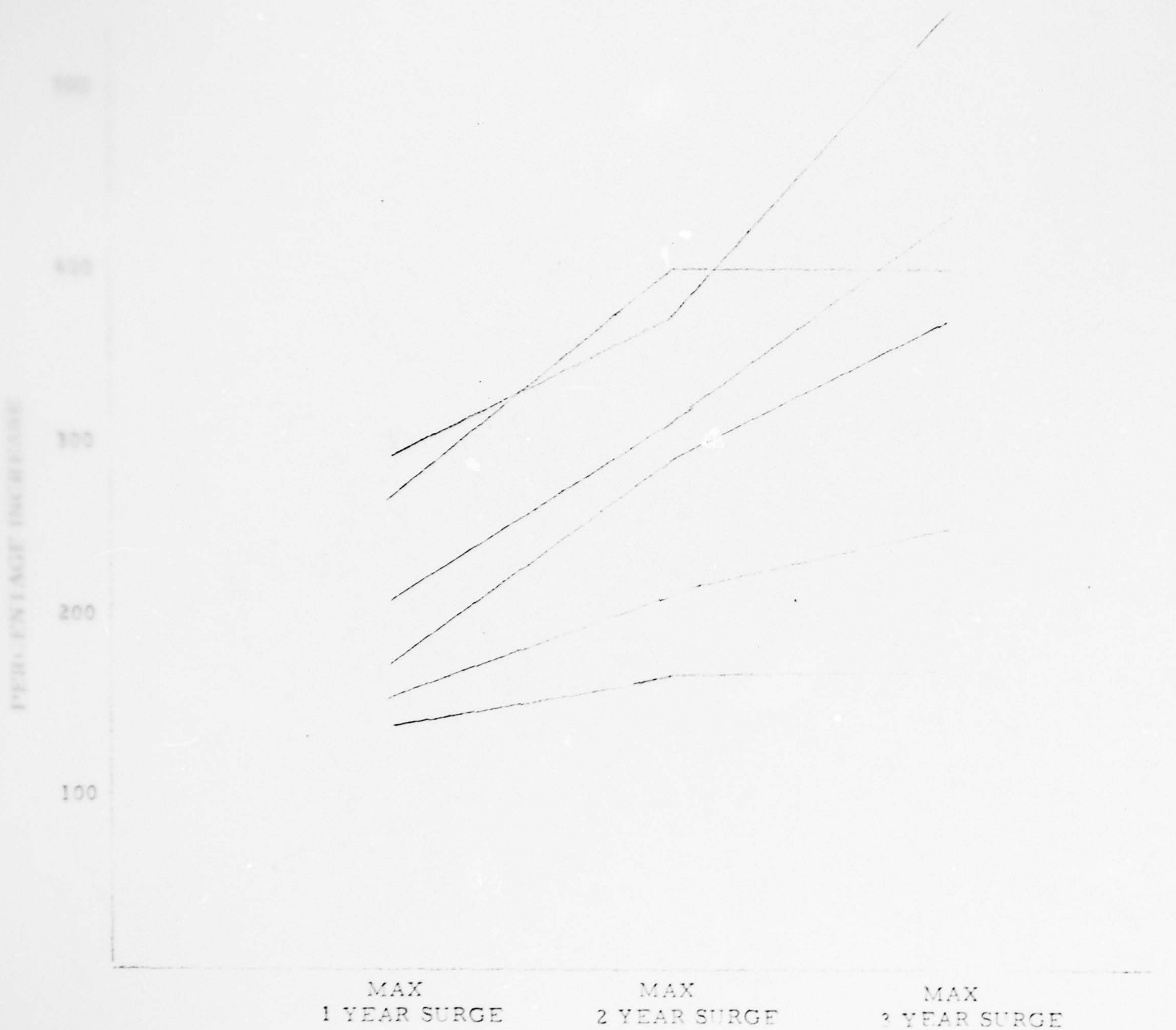
of Turbine Engine Manufacturers

Company	Maximum 1 Year Increase	Maximum 2 Year Increase	Maximum 3 Year Increase
1	157%	213%	249%
2	138%	163%	165%
3	212%	314%	433%
4	172%	293%	371%
5	295%	372%	556%
6	267%	400%	400%

[1/] Lbs.of engines used as measure of production

Source of Data: MATHTECH survey data.

Figure 2.13 - HISTORICAL MAXIMUM SURGE CAPABILITY OF INDIVIDUAL COMPANIES



Source of Data: Table 2.26.

The data shows that the one year surge rates vary by company from 1.38 to 2.95, the two year surge rates from 1.63 to 4.00 and the three year surge rates from 1.65 to 5.56. The surge ratio is dependent on the average size of the engine manufactured.

In the 1961-1975 period, the most rapid period of production expansion for the whole industry was from 1965 to 1967 when production increased 87 percent from 13.4 million pounds to 25.1 million pounds. The maximum production expansions in the 1961-1975 period over a 1, 2 and 3 year period were 9.0, 13.6 and 15.6 million pounds of engine. This production increase was made possible both by increased utilization of capacity as well as increased capacity. It does not represent a surge capability at constant facility and equipment. Thus, this historical experience may not be typical of what could be expected in a wartime surge since capacity expansion may have been planned in the 60's with a longer lead time than experienced in war. However, this experience might also underestimate surge capacity since these historical surge rates could reflect demand constraint.

Table 2.27 shows increased production rates for individual engines during the 1961-1975 period. The engines were selected by taking those engines having peak production in 1966-68 and having a substantial demand increase in that time period. The data shows that for smaller engines increased production rates ranged from 2 to 11 while for larger engines increased production rates range from 1.7 to 2.8. The difference in surge by engine size could, of course, reflect demand constraint as well as production capacity constraints.

Table 2.27

Surge Rates for Selected Engines
1961-1975

Approximate engine Weight (Lbs.)	Historical 2 Year Maximum Surge Rate
150	11.8
200	3.6
350	3.6
350	4.2
350	4.0
500	1.9
1800	2.0
2300	2.3
3200	1.7
3400	2.5
4500	1.8
4700	2.8

Source of Data: MATHTECH survey data.

Current surge capacity can also be measured by the ratio of peak production years to 1975 levels. Table 2.28 shows these ratios for the three measures of production capacity used here. The three measures are in good agreement and show that production could be increased by a factor of 2.6 under the following assumptions:

1) No productivity increases have occurred since 1967-1968,

2) Plant and machine capacity has not declined since 1967-1968 (previous charts show that physical space has probably not declined),

3) Labor, raw materials could be obtained, and

4) Subcontractor capacity that existed in 1967-1968 is still present.

Since military production is roughly 50 percent of total production currently, current military production could be expanded by a factor of 5.2 under these assumptions.

Table 2.29 shows the same ratios for each of the submarkets identified earlier. The data shows that for 0-2000 turboshaft, turboprop engines, current production could be expanded by a factor of 7.4 under the above assumptions, while in the largest submarket, 6-18 lbs. of thrust, production could be expanded by a factor of 3.4.

Table 2.28

RATIO OF PRODUCTION IN YEAR OF MAXIMUM INDUSTRY PRODUCTION TO 1975 PRODUCTION LEVEL

Lbs. of Engine	Lbs. of Thrust	Number of Engines
2.60[1]	2.56[1]	2.66[2]

1 Production year 1967

2 Production year 1968

Table 2.29

RATIO OF MAXIMUM PRODUCTION YEAR TO 1975 PRODUCTION

MARKET	
Turbojet, Turbofan[1]	
0 - 1	—
1 - 6	1.8
6 - 18	3.4
18 - 55	1.8
Turboshaft, Turboprop[2]	
0 - 2,000	7.4
>2,000	2.0

1 Lbs. of thrust (000)

2 SHP

APPENDIX A

The Aerospace Industry: Historical Trends

APPENDIX A

I. The Aerospace Industry: Historical Trends

A useful beginning point for understanding the state of the aircraft turbine engine industry is by analyzing the long-term trends in the aerospace industry as a whole. Table A. 1 shows an estimate of aerospace industry sales from 1950-1975. According to this estimate, the industry experienced almost continuous growth in terms of constant dollars from 1950 to 1968 with peak year in 1968 with 29.0 Billion sales. From 1968 to 1976, sales have declined 38 percent when measured in constant dollars. Current sales in constant dollars are the lowest since the early fifties. See Figure A. 1. The 1968-1976 experience is thus the first period of extended retrenchment experienced by the industry. The phenomena of very rapid growth and decline of aerospace industry demand leaves uncertain what level of demand will emerge over the next 10-15 years. An important related question is the extent to which future demand will exhibit relative stability or be characterized by surge demand such as the 1964-1968 peak.

The peak year of sales for commercial aerospace products was 1968 with 5.9 billion in sales. Figure A. 1 and A. 2, and Table A. 2 illustrates the trends in aerospace sales components in constant and current dollars respectively. The simultaneous peaking of these components was caused by a series of semi-independent decisions in the private and public sectors made in the late 50's and early 60's. NASA decisions for moon exploration in the early 60's created demand for NASA related aerospace products which peaked in 1966. These decisions

TABLE A.1

Aerospace Products Sales [1] in Current and Constant Dollars

Year	Current Dollars	Constant Dollars [2]
1950	3116	5809
1951	6264	10937
1952	10130	17465
1953	12459	21159
1954	12807	21455
1955	12411	20352
1956	13946	22171
1957	15858	24389
1958	16065	24319
1959	16640	24644
1960	17326	25230
1961	17997	25977
1962	19162	27161
1963	20134	28124
1964	20594	28323
1965	20670	27812
1966	24610	32061
1967	27267	34506
1968	28977	35094
1969	26149	30153
1970	24904	27259
1971	22154	23072
1972	22818	22818
1973	24809	23448
1974	26400	23647
1975	28373	22297
1976	29279	21884

1/

Aerospace Industries Association (AIA) estimates, based on latest available information. The AIA estimate of Aerospace induatry sales is arrived at by adding 1) DOD expenditures for "procurement" of aircraft and missiles, 2) DOD expenditures for research, development, test and evaluation for aircraft, missiles, and astronautics, 3) NASA expenditures for research and development, 4) AEC expenditures for space propulsion systems and space electric power development, 5) Net sales to customers other than U. S. Government by approximately 55 aerospace companies (adjusted to eliminate duplication by subcontracting) and 6) Non-aerospace sales reported by the approximately 55 aerospace companies reporting to the Bureau of Census.

2/

Implicit price deflators for Gross National Product (1972=100), Economic Report of the President, January 1977, Page 190.

Figure A.1

Trends in Aerospace Products and Sales
in Current and Constant (1972=100) Dollars
(millions of dollars)

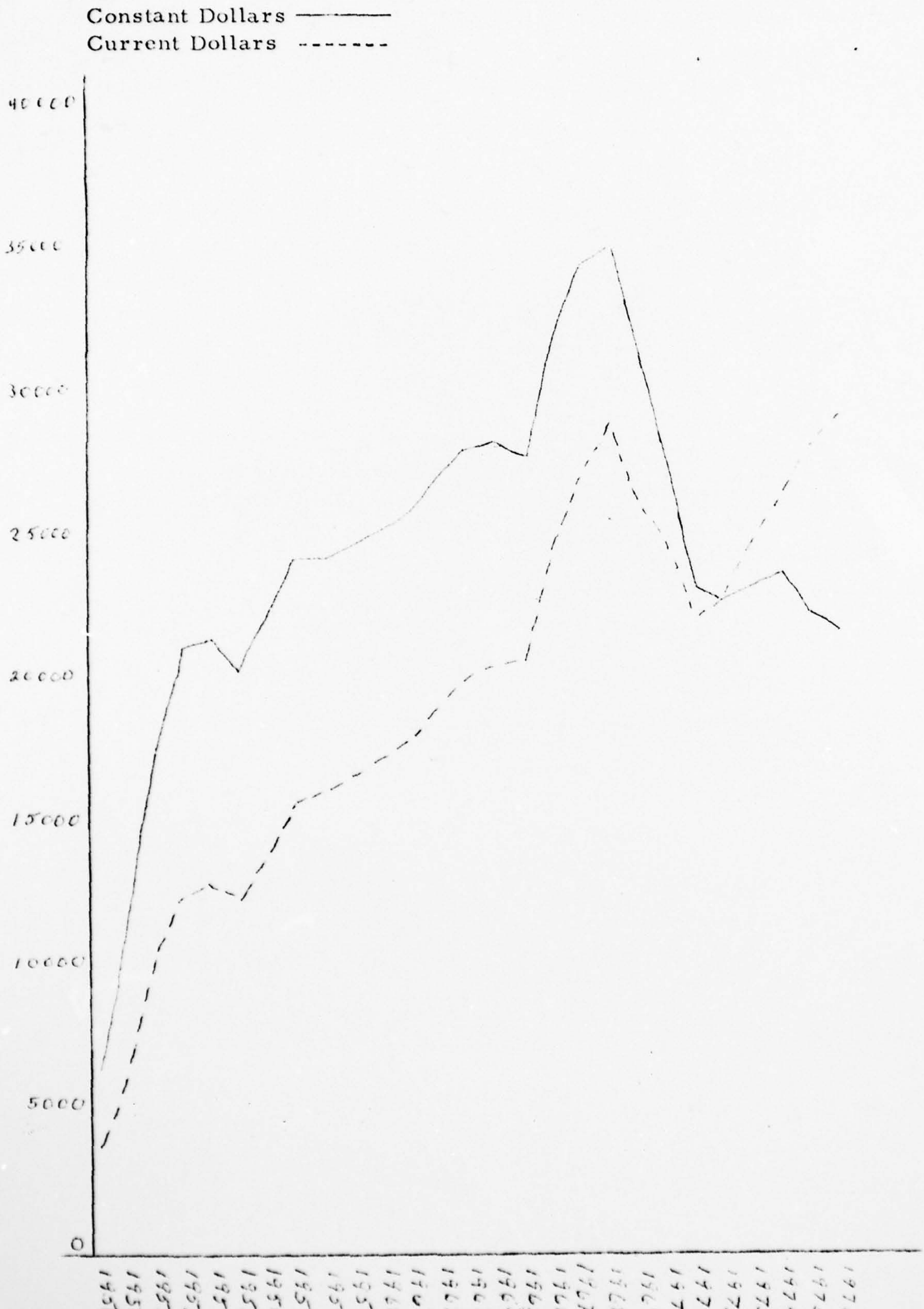
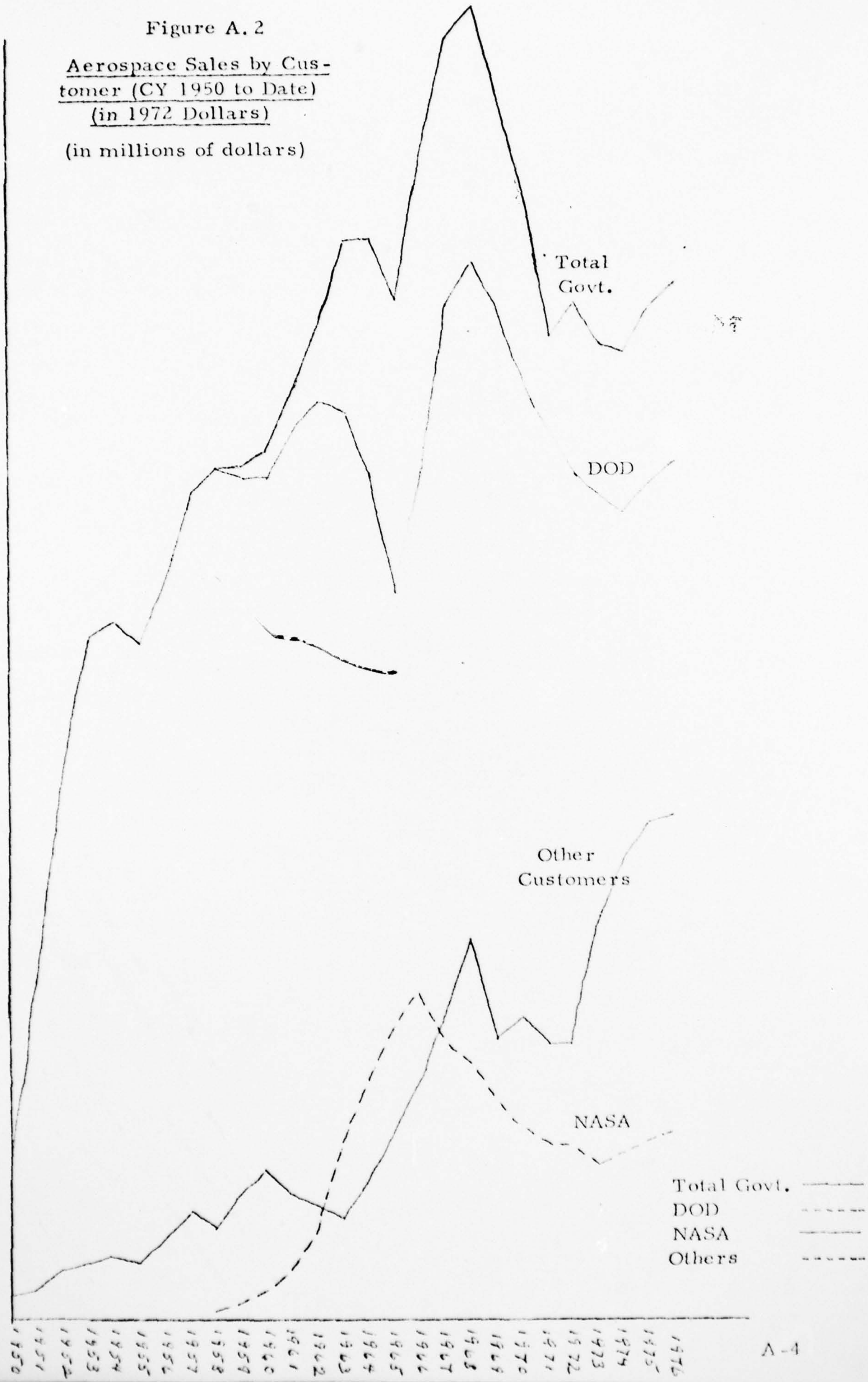


Figure A. 2

<u>Aerospace Sales by Customer (CY 1950 to Date) (in 1972 Dollars)</u>

(in millions of dollars)



were made at about the same time that DoD was making major weapon procurement decisions (Polaris, C5A, Minuteman, etc.) which would substantially boost DoD spending into the late 1960's. Vietnam war expenditures on top of these weapon procurement decisions boosted DoD aerospace spending to record levels in 1968. Commercial sales were aided by the tax policies of the Kennedy administration and rapid economic growth in 1962-1965 as well as rapid increase in demand for airline transportation beginning in 1962. The demand caused by the juxtaposition of these economic and political events and policies in the private and public sectors is unlikely to be duplicated outside of wartime. The end of the Vietnam war, reduced NASA expenditures and the combination of the energy crisis and recession have reduced all three components of aerospace sales in constant dollars substantially through 1974.

TABLE A-[illegible]

AEROSPACE INDUSTRY SALES BY CUSTOMER

CALENDER YEARS 1950 TO DATE

(Millions of Dollars)

Calender Year	Total Sales(1)	AEROSPACE PRODUCTS & SERVICES: Department of Defense (2)	NASA and Other Agencies(3)	Total Govt. (4)	Other Customers(5)	Non-Aerospace Products and Services(6)
1950	$ 3116	$ 2598	$ --	$ 2598	$ 238	$ 280
1951	6264	5353	--	5353	347	564
1952	10130	8568	--	8568	650	912
1953	12459	10604	--	10604	734	1121
1954	12807	10832	--	10832	822	1153
1955	12411	10508	--	10508	786	1117
1956	13946	11525	--	11525	1166	1255
1957	15858	12833	--	12833	1598	1427
1958	16065	13246	1	13247	1372	1446
1959	16640	13171	130	13301	1841	1498
1960	17326	13196	363	13559	2208	1559
1961	17997	13871	630	14501	1876	1620
1962	19162	14331	1334	15665	1772	1725
1963	20134	14191	2628	16819	1485	1830
1964	20594	13218	3635	16853	2020	1721
1965	20670	11396	4490	15886	2816	1968
1966	24610	13284	5026	18310	3663	2637
1967	27267	15855	4201	20056	4632	2579
1968	28977	16573	3908	20511	5917	2549
1969	26149	15771	3337	19108	4342	2699
1970	24904	14643	2974	17617	4643	2644
1971	22154	12584	2743	15329	4302	2523
1972	22818	13295	2608	15903	4269	2646
1973	24089	12886	2394	15280	6186	3343
1974 r	26400	12650	2527	15177	7136	4067
1975	28373	13127	2727	15853	7727	4792
1976	29279	13402	2815	16217	7808	5254

Source: Aerospace Industries Association estimates, based on latest available information. r - Revised

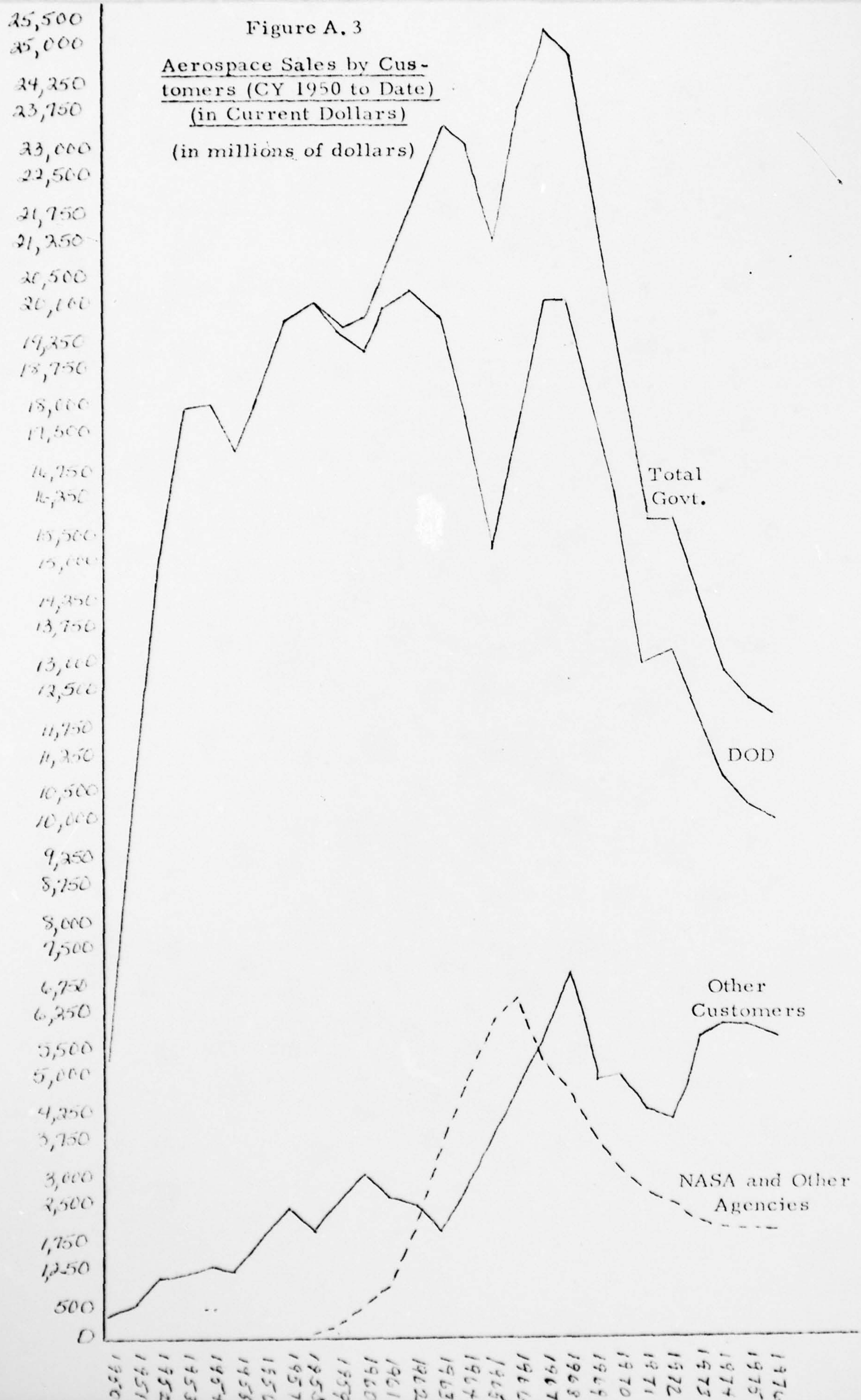


Figure A. 3
Aerospace Sales by Customers (CY 1950 to Date)
(in Current Dollars)
(in millions of dollars)
Total Govt.
DOD
Other Customers
NASA and Other Agencies

AD-A055 895 MATHTECH INC BETHESDA MD F/G 21/5
STUDY OF THE TURBINE ENGINE INDUSTRY.(U)
JAN 78 D W GRISSMER, K H KIM MDA903-76-C-0220
UNCLASSIFIED 7050-DG-KK-78-FR-1-DOD NL

2 OF 2
AD
A055 895

END
DATE
8-78
DDC

Table A.3

Comparison of Compound Growth Rates in Different Sectors

	1950-1968	
	Real Dollars	Constant Dollars
GNP	6.4	3.8
Federal Purchases of Goods and Services	9.5	5.6
Defense Spending	9.9	7.3
U.S. Government Aerospace Spending	12.1	9.5
Aerospace Industry Sales [1/]	13.2	10.5

1/ From data in Task 1

	1968-1975	
	Real Dollars	Constant Dollars
GNP	8.3	1.8
Federal Purchases of Goods and Services	3.5	-4.3
Defense Spending	1.3	-5.0
U.S. Government Aerospace Spending	-3.6	-10.2
Aerospace Industry Sales	-.5	-6.9

The growth and decline of sales in the aerospace industry can be put in better perspective by viewing it in relation to the growth in other components of the GNP. Since 1968 was the peak year of aerospace sales, compound growth rates have been calculated from 1950-1968 and 1968-1975 for different sectors. See Table A.3. The data shows that the aerospace industry experienced a 10.5 percent compound growth rate as measured in constant dollars from 1950-1968. This growth rate in constant dollars was almost 3 times the growth rate of the GNP and almost 1-1/2 times the growth rate of the defense sector. However, from 1968-1975 the industry has experienced in constant dollars almost a 7 percent compound rate of decline, compared to an annual compound growth rate of 1.8 percent in GNP.

A second aerospace industry sales estimate from 1961-1975 is given in Table A.4. This estimate is taken directly from industry reported data provided in the annual survey of manufacturers.* It includes data from approximately 70 companies. The data from this estimate shows that during the period 1961-1964, the government annually purchased between 77-81 percent of the total sales of these aerospace companies. Since 1963, the percentage of aerospace industry products sales to the government has declined to the 1975 level of 59 percent. Thus,

*The first estimate simply adds total government spending in aerospace plus commercial sales reported in the annual survey of manufacturers. The second estimate is taken entirely from the annual survey. The first estimate provides a better indication of total dollars spent in aerospace, while the second estimate provides more consistent data on a more well-defined (sic code) group of aerospace companies.

the government is still the dominant buyer in the market, although the dominance is less than the earlier period. The diversification in the industry is shown by the last column of Table A.2. From 1961 to 1976, non-aerospace products have grown as a percentage of industry sales from 8.2 percent to 16.2 percent.

Table A.5 shows more specific data for manufacturers of aircraft engines and parts. This engine category includes both piston and turbine engines as well as companies whose main products are parts of engines. Comparison of data in Table A.4 and A.5 shows that sales of aircraft engines historically comprise approximately 9-12 percent of aerospace industry sales. The data in Table A.5 also shows a somewhat lesser dependence on U. S. government procurement among engine manufacturers than aerospace companies in general. The percentage of total engine sales to the U. S. government has declined from 70-75 percent in the early 60's to 45-50 percent in the 1973-75 period.

Table A.4

Sales of Major Aerospace Companies

	Current Dollars	Constant Dollars (1972=100) 1/	Percentage of Actual Dollar Sales to U.S. Government	Non Aerospace Sales as Percent of Actual Dollars
1961	14.9	21.5	80.8	8.2
1962	16.0	22.7	78.6	9.0
1963	16.4	22.9	80.4	9.7
1964	16.7	23.0	76.8	10.3
1965	17.0	22.9	73.7	11.6
1966	20.2	26.3	71.8	13.0
1967	23.4	29.6	69.7	11.0
1968	25.6	31.0	65.0	10.0
1969	24.6	28.4	67.2	10.9
1970	24.7	27.0	66.3	10.7
1971	21.7	22.6	65.1	11.6
1972	21.5	21.5	62.8	12.3
1973	24.3	22.97	59.4	13.8
1974	26.8	23.0	56.6	15.1
1975	29.5	23.18	58.7	16.2

Source: Bureau of the Census, Current Industrial Reports Series MQ37D

1/ The price deflator is the implicit GNP price deflator, see Council of Economic Advisors, Economic Report of the President, Jan. 1977, p. 190, Table 13-3.

Table A.5

Sales of Seven Companies Manufacturing Aircraft Engines and Engine Parts
(millions)

Year	U.S. Government Current Dollars	U.S. Government (1975 Dollars)[1]	Other Current Dollars	Other (1975 Dollars)[1]	Total Current Dollars	Total (1975 Constant[1] Dollars)	Percentage U.S. Government
1960	913	1706	417	779	1330	2486	69
1961	1021	1884	433	799	1454	2683	70
1962	1130	2066	383	700	1513	2766	75
1963	1172	2139	404	737	1576	2876	74
1963	1066	1960	454	835	1520	2794	70
1965	1132	2077	582	1068	1714	3144	66
1966	1372	2459	723	1296	2095	3754	65
1967	1796	3111	1016	1758	2812	4865	64
1968	1714	2842	1251	2075	2965	4917	58
1969	1779	2806	1086	1713	2865	4518	62
1970	1912	2854	1197	1787	3109	4441	61
1971	1360	1929	986	1399	2346	3328	58
1972	1288	1752	1114	1516	2402	3268	54
1973	1308	1649	1417	1787	2725	3436	48
1974	1420	1601	1714	1932	3134	3440	45
1975	1362	1362	1689	1689	3051	3051	45

Source: Current Industrial Reports, Forms M37C "Aircraft Engines", Aeronautical Economic Escalation Indices, July, 1975, Directorate of Cost Analysis, Aeronautical Systems Division, Wright Patterson AFB, Ohio - Price deflators used are developed for aircraft engines specifically.

Sales data in Table A. 5 for engine manufacturers shows peaks for U.S. government sales in 1967 and commercial sales peaks in 1968 in constant dollars. The engine data displays a larger source component than the aerospace industry as a whole. The peak year of 1968 for the engine companies represents a larger percentage increase over 1961 or 1975 levels than the corresponding percentage for the aerospace industry. This increased peak and more severe cyclical nature of revenues is probably attributable to the narrowness of product lines for the engine companies compared to the aerospace industry as a whole.

Table A.6 compares the sales of aircraft engine companies to GNP. In the period 1961-66, engine sales remained a fairly constant percentage (.24-.28) of GNP. During the peak production period of 1967-1970, percentage contribution to the GNP jumped to .31-.35. The severe decline since 1970 places the percentage at .20-.22.

Table A. 6

Comparison of Aircraft Engine and Parts Sales to GNP

	GNP	Aircraft Engine and Parts Sales	Percentage of GNP
60	506	1.330	.26
61	523	1.454	.28
62	564	1.513	.27
63	595	1.576	.26
64	636	1.520	.24
65	688	1.714	.25
66	753	2.095	.28
67	796	2.812	.35
68	869	2.965	.34
69	936	2.865	.31
70	982	3.109	.32
71	1063	2.346	.22
72	1171	2.402	.21
73	1306	2.725	.21
74	1407	3.134	.22
75	1499	3.051	.20

III. Aerospace Industry: Profitability

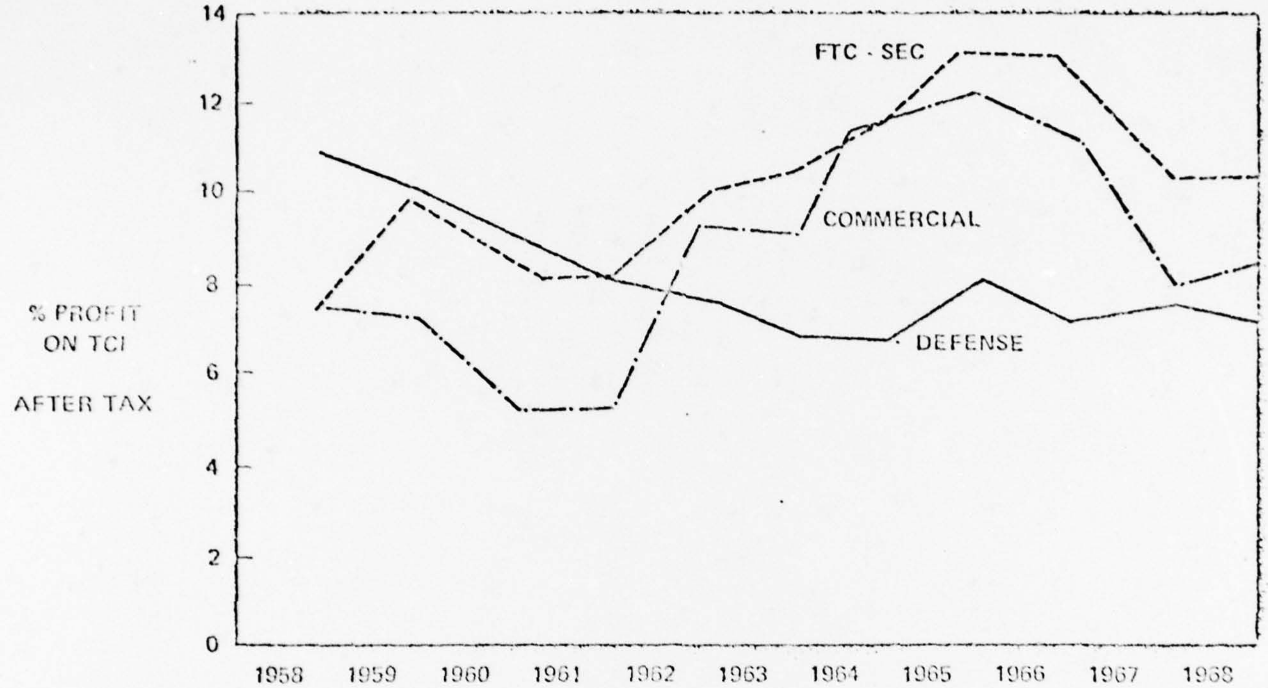
Three sources of data have been examined to view the financial health of the aerospace industry. The 1971 GAO study examined the profits of 74 large DoD contractors during the period of 1966-69. [1/] Profits were measured as a percentage of sales, total capital invested (TCI) and equity capital investment (ECI). All three measures showed a higher return on commercial work than on government contracts. For example profits on DoD contracts averaged 4.3% of sales over the 4 years but profits on comparable commercial work of the 74 contractors averaged 9.9% of sales. When profit was measured as a percent of the total capital investment (total liabilities plus equity, exclusive of Government Capital), the difference narrowed: 11.2% for DoD sales and 14.0% for commercial sales.

The GAO findings were supported by the findings of a similar study of the 1958-1967 period by the Logistics Management Institute (LMI). The LMI study covered defense business, commercial business performed by defense industry, and FTC-SEC business (durable goods manufacturers whose business is comparable with that of firms in defense industry). Figure 4 shows the findings of the LMI study.

1/ Comptroller General of the United States, Defense Industry Profit.

Figure A. 4

PROFIT ON TOTAL CAPITAL INVESTMENT
MAJOR DEFENSE COMPANIES



DEFENSE % PROFIT ON TCI	10.1	9.5	8.7	7.5	7.4	6.5	6.3	7.6	7.0	7.3	6.8
COMMERCIAL % PROFIT ON TCI	7.0	6.8	4.8	4.7	9.0	8.7	10.9	11.6	10.0	7.4	8.3
FTC–SEC % PROFIT ON TCI	7.1	9.3	7.8	7.4	9.3	9.8	10.8	12.6	12.4	10.1	10.?

Source: Logistics Management Institute, Defense Industry Profit Review, 1968 Profit Data, March 1970, p. 11.

The Federal Trade Commission has also estimated net profit after taxes as a percent of sales for manufacturing corporations, including the aerospace industry. The result is shown in Table A.8. The results show a consistently lower net profit as a percent of sales for aerospace companies.

Table A.8

NET PROFIT AFTER TAXES
AS A PERCENT OF SALES
FOR MANUFACTURING CORPORATIONS

Calendar Years 1960 to Date

Year	All Manufacturing Corporations[a]	Non-Durable Goods	Durable Goods	Aerospace
1960	4.4%	4.8%	4.0%	1.4%
1961	4.3	4.7	3.9	1.8
1962	4.5	4.7	4.4	2.4
1963	4.7	4.9	4.5	2.3
1964	5.2	5.4	5.1	2.6
1965	5.6	5.5	5.7	3.2
1966	5.6	5.5	5.6	3.0
1967	5.0	5.3	4.9	2.7
1968	5.1	5.3	4.9	3.2
1969	4.8	5.0	4.6	3.0
1970	4.0	4.5	3.6	2.0
1971	4.1	4.5	3.8	1.8
1972	4.4	4.6	4.3	2.4
1973	4.7	5.0	4.5	2.9
1974[r]	5.5	6.4	4.7	2.9
1975	4.6	5.1	4.1	2.9

Source: Federal Trade Commission, "Quarterly Financial Report for Manufacturing Corporations."
[a] Does not include newspapers.
[r] Revised.

One major consequence of low profits in the aerospace industry will be the difficulty in attracting equity capital investment. This means the aerospace firms should borrow at a higher rate of interest as their credit rating gets lower. In many cases, the interest payments are not compensated by the government, thus driving profits lower. Furthermore, the low equity/debt ratios increase not only the risk premium component of interest rate but also the risk of equity investment itself and depress the price/earnings ratios in stock market. The net result is (1) to make capital financing more difficult, (2) to make financially weak firms to leave the industry. Of the surviving firms, some will be forced to reduce their production while others will diversify their products to more commercial programs.

APPENDIX B

Economic Concentration and Capacity Utilization In the Aircraft Engine Industry

APPENDIX B

Economic Concentration and Capacity Utilization in the Aircraft Engine Industry

INTRODUCTION

The concentrated sector operates under principles of its own that are not only different from but often the reverse of those applicable to competitive industries. A major purpose of this chapter is an empirical exploration of the principles governing the behavior of the highly concentrated aircraft engine industry. We will examine first the extent of concentration and secondly we will be concerned with causal factors which determine capacity utilization. The concentration we are dealing with in the aircraft engine industry is "market concentration", that is, the control of a given market by a small number of leading producers in an industry. Here, we are analyzing a substantial share of the market by a "Big Three", "Big Five", or "Big Ten", or the like. Economists call such a market "oligopolistic". The oligopolistic market control originates from:

(1) Technology requiring heavy capital investment

(2) High costs of promotion-advertisement and sales efforts

(3) High costs caused by various governmental restrictions in procurement regulations.

In an oligopolistic industry, the sensitivity of a firm to its rivals makes it "very aware of being in competition actively or potentially."[1]

---

[1] Fritz Machlup, The Economics of Seller's Competition, Johns Hopkins Press, 1952, p. 353.

Thus a small number of firms in an industry does not necessarily mean reduced competition. In fact, the competition in the aircraft and its engine industry takes various forms and is most fierce among many of the oligopolistic industries in the United States. For example, the competition in the aerospace industry is not classic price competition. It is often replaced or supplemented by the various forms of non-price competition in terms of quality, new technology, service, advertising, design, system characteristics, alternative hardwares for essentially the same mission (e.g., B-1 bombers vs. cruise missiles).

The fierceness of competition in the aerospace industry can be illustrated by the halting of B-1 bomber production. On June 30, President Carter decided to halt B-1 bomber production. As a result, Rockwell International laid off 10,000 employees and potentially lost sales ranging from \$26.5 billion to \$32 billion (\$1.5 billion for five prototype B-1 bombers plus 244 planes at \$102 million each when a full production schedule was in effect) over the next 10 to 15 years. In the B-1 bomber case, the price was a factor, but the competing cruise missiles for achieving the same mission was the major factor. Due to the cancellation of the B-1, Boeing (for the Air Force) and General Dynamics (for the Navy Tomahawk) are competing with each other for cruise missile contracts. The stake is anywhere between \$2 and \$3 billion (each cruise missile costing \$.75 to \$1 million). According to the Wall Street Journal (13 July 1977, p. 4), earlier in 1977, the Pentagon originally decided to use the Boeing-developed

cruise missile for the Air Force and possibly continue to develop and produce a Navy-General Dynamics version for use from ships and submarines. However, the Pentagon rejected the Navy-General Dynamics version for the Air Force Bombers. With President Carter's decision to accelerate development of the air-launched cruise missile, it seemed as if Boeing was in a favorable position within the Pentagon to get the contract. But the Pentagon has reversed its previous position and plans to place both Boeing and General Dynamics in competition to develop the air-launched version. As a result, the Boeing officials were bitter and charged that General Dynamics has mounted "an absolutely dirty campaign" at the Pentagon. But General Dynamics stressed that the company has had more successful tests of its model than the Boeing's version.

The above descriptions of the B-1 decision and the shift to cruise missiles illustrate how the fortunes of the aerospace market can be swung by a single governmental decision and how the competition is shaping up between the two cruise missile producers in terms of non-price competition. In the cruise missile case, neither company enjoys a clear cut favor from the Pentagon. Under such a circumstance, a unilateral price increase in the cruise missile will create a great amount of uncertainty for both companies.

One of the interesting questions is how the oligopolistic aerospace industry in general and the engine industry in particular behave during

various stages of the business cycles or during changing levels of the DOD procurement. Since there is no established single, dominant leader year after year in the aerospace industry and when the demand is below capacity output, price competition would be non-existent. This is also true when the demand is near but below the capacity level.

ECONOMIC CONCENTRATION AND ITS EFFECTS

In this section, we chose 19 sectors of the economy (17 4-digit SIC's, fuel-related products and power, and all commodities) to see what relationships exist among price, capacity utilization, output, and market concentration ratio. The industries (by 4-digit SIC) are chosen, if in 1972 they had 60% or more of the share of value of shipments accounted for by the 4 largest companies.[1/]

SIC 2271 = Woven carpets and Rugs
SIC 2279 = Carpets and Rugs, NEC[2/]
SIC 2822 = Synthetic Rubber (Vulcanized Elastomers)
SIC 2823 = Cellulosic Man-Made Fiber
SIC 2824 = Synthetic Organic Fibers, Except Cellulosic
SIC 2833 = Medicinal Chemicals and Botanical Products
SIC 3211 = Flat Glass
SIC 3331 = Primary Smelting and Refining of Copper
SIC 3332 = Primary Smelting and Refining of Lead
SIC 3333 = Primary Smelting and Refining of Zinc
SIC 3334 = Primary Production of Aluminum
SIC 3511 = Steam, Gas, Hydraulic Turbines and Turbine Generator Set Units
SIC 3694 = Electrical Equipment for Internal Combustion Engines
SIC 3711 = Motor Vehicles and Passenger Carbodies
SIC 3721 = Aircraft
SIC 3724 = Aircraft Engines and Engine Parts
SIC 3743 = Railroad Equipment

1/ U.S. Department of Commerce, Bureau of the Census, Census of Manufacturers, 1972, Special Report Series: Concentration Ratios in Manufacturing, MC72(SR)-2, U.S. Government Printing Office, Washington, D.C. 1975.

2/ NEC = Not Elsewhere Classified.

Using the data in Tables B.1 and B.2, we calculated (1) the price change during the 1972-76 period, ΔP, (2) the average actual capacity utilization as a % of practical capacity for 1 and 4 and 1 and 5,[1/], C, (3) percent change in market share of top 4 companies in each industry, ΔS, and (4) fluctuations in the value of shipments during 1970-1976, $x_1=0$ if output is down (otherwise $x_1=1$) and $x_2=1$ if output is up (otherwise $x_2=0$).

We made a cross-section regression analysis of the following 14 industries[2/]:

SIC = 2822	SIC = 3511
SIC = 2823	SIC = 3694
SIC = 2824	SIC = 3711
SIC = 2833	SIC = 3721
SIC = 3211	SIC = 3724
SIC = 3331	SIC = 3741
SIC = 3333	
SIC = 3334	

The result shows that there is a substantial influence of both capacity and market concentration on price change.

More specifically,

$$\Delta P = -78.73332 + \underset{\substack{(.80083) \\ (t=1.95)}}{1.573376C} + \underset{\substack{(.62535) \\ (t=2.95)}}{1.846496\,\Delta S} \qquad R^2=.43 \quad F=4.53 \qquad (1)$$

1/ At the time of the caluclation, the capacity utiliztion data was not available for 1976.

2/ For other industries in Tables B.1 and B.2, we did not have all the necessary information.

Table B.1 - Price Indices of Selected Economic Sectors
1958-1976 (1972=100)

	Price Index by 1972 SIC Code and Products (1972=100)																		
Year	3721	3724	All commodities wholesale	fuel-related products and power	2271	2279	2822	2823	2824	2833	3211	3331	3332	3333	3334	3511	3694	3711	3743
1958	73.8	72.9	79.4	80.4	109.8	108.9	NA	95.7	129.1	153.1	85.6	59.2	67.9	65.9	88.5	70.6	69.0	81.4	82.8
1959	74.6	73.9	79.6	80.4	102.3	109.5	NA	96.2	129.1	134.6	85.4	63.6	73.1	76.0	95.1	71.0	70.1	82.9	82.8
1960	75.2	75.4	79.6	81.0	99.7	111.5	NA	91.2	121.7	125.7	83.2	67.2	77.1	74.7	100.4	71.0	69.8	80.8	82.8
1961	75.2	75.2	79.3	82.0	98.7	110.7	NA	90.1	119.5	113.8	80.8	63.5	72.9	70.7	94.9	69.0	69.6	80.8	82.8
1962	75.2	75.2	79.6	81.5	101.7	108.2	NA	86.5	118.7	98.3	79.3	62.4	71.7	69.5	93.3	68.8	71.2	80.2	83.0
1963	78.2	74.5	79.3	81.2	94.2	108.3	103.6	90.6	118.7	101.9	78.6	62.6	71.9	69.7	93.6	69.1	71.3	79.8	83.0
1964	76.9	77.2	79.5	79.0	100.8	115.2	99.3	92.5	114.4	100.1	80.6	65.3	88.1	78.8	98.2	70.1	71.1	79.6	82.9
1965	78.6	77.8	81.1	80.5	98.0	111.0	99.3	92.7	109.6	100.0	79.5	71.5	103.6	84.2	101.4	70.2	73.7	80.4	83.8
1966	80.3	79.7	83.8	82.5	98.4	111.4	99.4	93.2	108.4	101.4	79.1	72.9	97.6	84.2	101.4	72.4	74.6	80.8	83.8
1967	82.9	82.1	84.0	84.3	94.6	106.8	98.9	94.0	103.2	99.0	82.9	77.0	90.9	80.3	103.4	77.0	79.4	82.6	85.2
1968	85.7	83.6	86.1	83.4	95.6	106.2	97.9	94.3	101.3	96.2	86.4	87.7	86.2	78.0	106.7	79.7	83.8	85.3	85.6
1969	89.0	87.6	89.4	85.1	95.6	105.2	99.3	95.3	101.4	NA	90.7	93.2	97.0	84.4	112.4	84.5	87.3	87.5	86.0
1970	94.5	92.2	92.7	89.5	95.8	103.2	99.8	95.5	101.2	NA	96.0	113.6	103.5	88.0	NA	92.4	92.7	91.5	87.5
1971	98.3	95.6	95.6	96.3	94.3	100.7	99.7	96.7	100.2	NA	102.2	102.4	90.7	90.7	NA	96.8	98.4	97.8	92.6
1972	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	102.7	100.0	100.0	100.0
1973	103.8	103.5	131.1	113.2	122.0	104.8	100.7	102.3	102.1	100.5	98.2	115.7	106.8	121.2	104.6	100.7	101.9	100.8	103.3
1974	115.2	117.6	134.4	175.6	144.0	114.8	129.5	117.0	107.0	112.0	101.7	151.0	145.2	206.0	155.9	113.5	111.8	108.2	123.1
1975	136.9	142.5	146.9	206.7	144.8	118.8	144.7	127.2	103.5	127.1	107.1	125.6	144.1	213.2	165.3	145.4	133.0	117.9	149.3
1976	142.6	154.6	153.6	223.9	144.8	122.1	153.3	132.4	104.8	133.5	114.8	134.6	153.2	206.6	132.3	166.7	142.9	125.5	157.5

1/ Source of data: For the prices of all commodities and fuel and related products and power, Council of Economic Advisors, Economic Report of the President, Washington, D.C., January 1977. All other prices are from the unpublished BLS data.

Table B.2 - Capacity, Output, Market Concentration of Selected Industries

Data Item	All commodities	2271	2279	2822	2823	2824	2833	3211	3331	3332	3333	3334	3511	3694	3711	3721	3724	3743
		SIC																
Actual output as % of capacity (4th quarter): 1/																		
1973 preferred rate		D	NR	D	NR	89	D	89	91	NR	D	98	100	84	95	64	78	96
1973 practical rate		D	NR	D	NR	88	D	89	94	NR	D	98	84	84	93	60	72	93
1974 preferred rate		73	NR	75	70	71	90	73	87	D	89	100	101	86	78	68	84	89
1974 practical rate		62	NR	68	70	70	82	72	86	D	89	101	92	85	76	61	68	84
1975 preferred rate		D	NR	79	73	81	92	78	78	D	72	59	93	87	84	59	78	82
1975 practical rate		D	NR	79	73	88	81	77	78	D	72	59	85	84	82	52	65	76
1976 preferred rate		D	NR	96	100	99	94	97	100	D	100	100	93	97	98	88	84	93
1976 practical rate		D	NR	78	72	77	85	73	80	D	85	84	81	93	84	52	62	69
Market share (%) by Top 4 Companies 2/:																		
1972		78	78	62	96	74	59	92	72	93	66	79	90	65	93	66	77	97
1963		67	32	57	82	94	68	94	78	D	57	D	93	69	92	59	57	97
Increase or decrease of value of shipment during 1972-1976	↑ + ↓	↓	↓	↑ + ↓	↑ + ↓	↑ + ↓	↑	↓	↓	↑ + ↓	↓	↓	↑ + ↓	↑ + ↓	↑ + ↓	↑ + ↓	↑ + ↓	↑ + ↓

1/ U.S. Department of Commerce, Bureau of the Census, *Industry Division*. *For 1975 data in* Survey of Plant Capacity, 1975 Supplement, MQ-C1(75)-2, U.S. Government Printing Office, the data for other years are from the unpublished Census data.

2/ U.S. Bureau of the Census, Census of Manufacturers, 1972, Special Report Series: Concentration Ratios in Manufacturing, MC72(SR)-2, U.S. Government Printing Office, Washington, D.C. 1975.

Symbols: NR = Not responded to survey
D = Not disclosed
↓ = down ↑ = up ↑ + ↓ = up and down

Note: 1. Practical capacity is the greatest level of output the plant could achieve within the framework of a realistic pattern.
2. Preferred capacity is an intermediate level of operations between actual operations and practical capacity.

As we can see the variables representing changes in the value of shipments had no statistically significant relationship.

Listed below is the matrix of the correlation among the five variables.

Table B.3 Correlation Coefficients

	ΔP	C	ΔS	x_1	x_2
ΔP	1.0				
C	.12613	1.0			
ΔS	.49940	-.48953	1.0		
x_1	-.08718	-.17831	.02271	1.0	
x_2	-.11739	.16251	-.27607	.16116	1.0

From Table B.3, it can be seen that an increase in market concentration (ΔS) has the greatest but negative influence on capacity utilization (C). This confirms a monopolistic tendency in the oligopolistic market where capacity utilization is diminished as the firms market concentration rate increases.

We also analyzed the relationship among price, capacity utilization, and market concentration rate for the aircraft industry.[1/] Since the market concentration rate has changed little (for top 4 companies 59% in 1947 to 66% in 1972;

1/ No capacity utilization data is available for 1961 through 1975 for SIC 3724 (Aircraft Engines and Engine Parts).

for top 8 companies 83% in 1947 to 86 in 1972, and for top 20 these have been constant at 99% during 1947-1972), we omitted the variable representing market concentration ratio. Note that for SIC 3724 (Aircraft Engines and Engine Parts) the concentration ratio has not changed much during 1949-1972. Table B.4 is the data used for analyzing SIC 3721 (Aircraft) as shown in Equation (2).

Table B.4

Capacity Utilization and Price of Output for Aircraft Industry

Year	Actual Capacity Utilization 1/	Price (1972=100) 2/
1961	55	75.2
1962	47	75.2
1963	45	78.2
1964	59	76.9
1965	60	78.6
1966	70	80.3
1967	90	82.9
1968	95	85.7
1969	70	89.0
1970	77	94.5
1971	60	98.3
1972	50	100.0
1973	60	103.8
1974	57	115.2
1975	50	136.7

1/ OMB/DoD, Aircraft Industry Capacity Study (Final Draft), 17 November, 1976, Exhibit 18, p. 45, in (AMPR WT) lbs. in millions.

2/ From Table B.1.

$$\text{actual capacity utilization} = \underset{\substack{(21.74124)\\(t=3.54)}}{76.92134} - \underset{\substack{(.23400)\\(t=.65)}}{.15235}\ \text{Price} \quad R^2 = .03158 \qquad (2)$$

The result of the regression analysis using the data in Table B.4 suggests that actual capacity utilization is invariant with respect to price movements. In fact, the strong t-value of the estimated constant reflects that price was not a factor during the period (1961-1975) when the U.S. aircraft industry operated under "nominal capacity".[1/]

We also examined the relationship between capacity utilization of U.S. aircraft and general aviation industries and composite profits of the aerospace industry as a whole. Table B.5 lists the data used for the regression analysis between capacity and profit margin.

Table B.5

Capacity Utilization and Profit Margins in U.S. Aircraft and General Aviation[2/]

Year	Actual Capacity Utilization (AMPR WT lbs. in millions)	Profit as % of sales
1963	60	7.7
1966	73	6.6
1967	89	6.1
1968	93	6.4
1969	70	6.5
1970	76	5.1
1971	64	5.2
1972	50	6.6
1973	58	6.9
1974	57	7.1

1/ See OMB/DoD, Aircraft Industry Capacity Study (Final Draft), 17 November 1976, Exhibit 18, p. 45.

2/ Source of Data: (a) Utilization is from OMB/DoD, Aircraft Industry Capacity Study (Final Draft), 17 November 1976, Exhibit 17, p. 44.
(b) Profit is from Standard and Poors, The Outlook: Sales Gains to Taper Off by End of 1976, 1975, p. A33.

We obtained the following regression estimate

$$\text{capacity utilization} = \underset{\substack{(37.303)\\(t=2.98)}}{111.08} - \underset{\substack{(5.77)\\(t=1.14)}}{6.56}\ \text{profit} \qquad R^2 = .14 \tag{3}$$

The result is very similar to the regression using capacity utilization and price of output. Thus, capacity is not affected by price or profit when operating below capacity.

Using Equation (1), we derive the following relation:

$$C = 50.0410 + .6356\Delta P - 1.1736\Delta S \tag{4}$$

where, as before,

C = the average actual capacity utilization as % of practical capacity in 1974 and 1975

ΔP = price change during the 1972-76 period

ΔS = percent change in market share of top 4 companies

At the mean values of

$\Delta P = 43.71$

$\Delta S = 0.60$ for the sample industries

$\hat{C} = 77.1\%$.

When Equation (4) is applied to SIC 3721 (Aircraft) and SIC 3724 (Aircraft Engines and Engine Parts), using the actual values of ΔP and ΔS, we obtained the following results:

	SIC 3721	SIC 3724
ΔP =	42.6%	54.6%
ΔS =	7%	20%
$\hat{C}$ =	68.90%	61.27%

The 68.90% of practical capacity for SIC 3721 (which was estimated at 126 million lbs. in AMPR WT (Aeronautical Manufacturers' Planning Report Weight) for the period of 1960-1990, according to OMB/DoD study)[1/] is 86 million lbs. in AMPR WT in 1974-75. The same study estimated three different levels of alternate capacity see Table B.6.[2/]

Table B.6

Aircraft Capacity

Alternate Capacity Levels	Employment (Thousand)	Sales (Billion 1976 $)	Output (AMPR Wt. in Millions of lb.)
Nominal One-Shift Capacity (1 shift - 40 hr wk)	360	19	100
"Peak" Corporate Experiences (1.4 shifts - 40 hr wk.)	470	25	125
Mobilization Capacity (3 shifts - 48 hr wk)	990	53	220
1974/75 Actual Performance	NA	NA	54
1975/76 Actual Performance	200	11	50

1/ See OMB/DoD, op.cit. Exhibit 18, p.45. This report defines "peak" capacity as peak corporate experience (1.4 shifts - 40 hr/wk).

2/ Ibid. pp.2 and p. 45.

The difference between our estimate of actual capacity utilization as a percent of peak (or practical capacity) at 86 million lbs. and the OMB/DoD figures of 54 million lbs. (a difference of 32 million lbs.) in AMPR WT for the period of 1974-75 may be due to several reasons. They are:

(1) Probable differences in the definitions of "capacity", utilization, used by the Census Bureau, aerospace companies, and OMB/DoD.

(2) The lack of a strong, convincing empirical relationship among capacity utilization, market concentration, and price changes.

(3) When there is a great uncertainty as to purchases made by U.S. Government and when output levels have been below the peak (or practical) and nominal capacity, *there are weak relationships* between capacity utilization and price level.

AIRCRAFT ENGINES AND PARTS: CAPACITY AND UTILIZATION

There is a relationship between aircraft sales and sales of engines for aircraft. We have estimated the ratio of engines and parts (SIC 3724) and aircraft (SIC 3721) as shown in Table B.7. This ratio was estimated for use in the estimates of surge and mobilization capacities of SIC 3724.

Table B.7

Sales of Aircraft, Aircraft Engines and Parts, and Capacity Utilization of Aircraft Engine (Turbine) Industry [1/]

Year	Sales of Aircraft ($ million) (1)	Sales of Aircraft Engines and Parts ($ million) (2)	Ratio of Engines to Aircraft Sales (3)=(2)/(1)	Lbs. of Engine (million) (4)	Lbs. of Thrust (million) (5)
1961	4,401	1,454	.3304	14.4	56.8
1962	4,387	1,513	.3349	14.0	53.0
1963	4,041	1,576	.3900	12.8	48.9
1964	4,911	1,520	.3095	13.3	56.6
1965	5,343	1,714	.3208	13.4	59.9
1966	6,630	2,095	.3160	18.1	81.2
1967	9,082	2,812	.3096	25.2	111.4
1968	10,885	2,965	.2724	23.3	101.9
1969	9,899	2,865	.2894	19.0	85.6
1970	10,357	3,109	.3002	18.0	83.3
1971	5,433	2,346	.4318	12.7	55.9
1972	7,751	2,402	.3099	8.7	34.1
1973	9,553	2,725	.2853	9.6	39.8
1974	10,408	3,134	.3011	10.0	46.8
1975	11,270	3,386	.3004	9.7	43.5
1976	12,240	3,855	.3150		

1/ Turbine engine only.

Source of Data: (a) Cols. 1 and 2 are from Aerospace Industries Association of America, Aerospace Facts and Figures, 1977/88, p. 31.

(b) Cols. 4 and 5 are from MATHTECH's data collected from the firms in the aircraft engines and parts industry.

The ratio of sales of aircraft (Col. 1) and those of engines (Col. 2) is estimated in Table B.7. We have the following estimated regression between Col. 1 and Col. 2:

$$\text{Sales of aircraft} = \underset{\substack{(643.18) \\ (t=1.73)}}{-1113.3693} + \underset{\substack{(.24995) \\ (t=14.64)}}{3.6585}\,(\text{sales of engines and parts})\; R^2 = 94 \qquad (5)$$

At the mean value of sales of engine at \$2.466 billion, the value of sales of aircraft is \$7.911 billion. The average ratio of the dollar value of engine sales to aircraft sales is, thus, .3117. Thus, there is a strong basis for using aircraft capacity index for developing surge and mobilization capeity for aircraft engines and parts.

We assume that the 1967 estimated capacity utilization of the aircraft engines *and parts industry* shown in Table B.7 is the nominal one-shift capacity (1 shift - 40 hours/week), which is either 25.2 million lbs. of engines or 111.4 million lbs. of thrust. This nominal capacity along with capacity utilization for the years 1961-76 are shown in Figure B.1. As you can see from Figure B.2, it does not matter much which measure out of the three measures (i.e., *weight, number, and thrust of engine*) is used. In projecting both the mobilization capacity and peak surge capacity, we used the assumption embodied in OMB/DoD Study. 1/ Since there is an almost fixed relationship between aircraft sales and engine sales, we think that the use of the assumption in the OMB/DoD study is a reasonable one.

1/ Ibid, p. 45.

Figure B.1

Capacity Utilization in U.S. Aircraft Engines and Parts (SIC 3724)

(in million pounds of thrust)

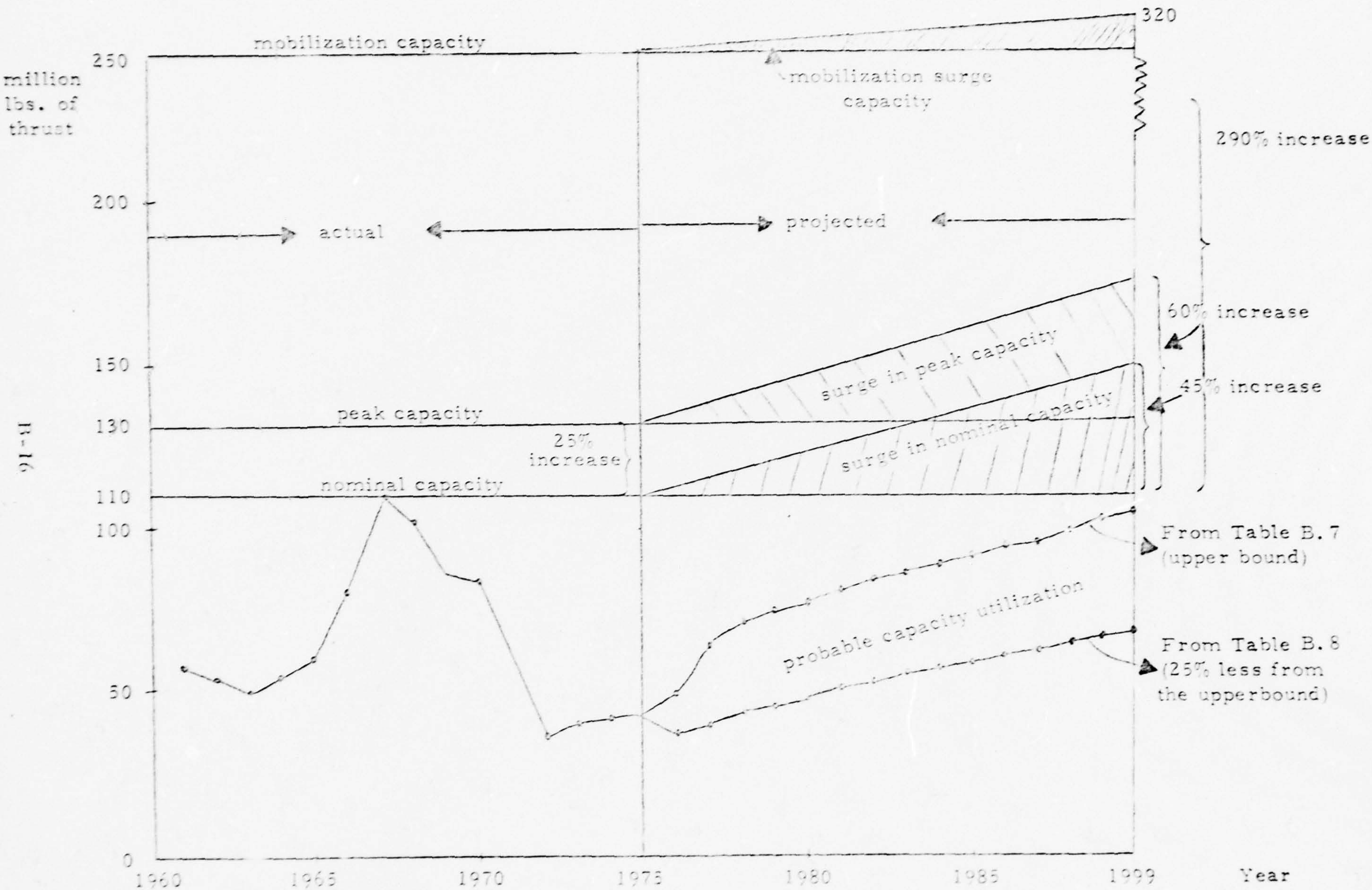
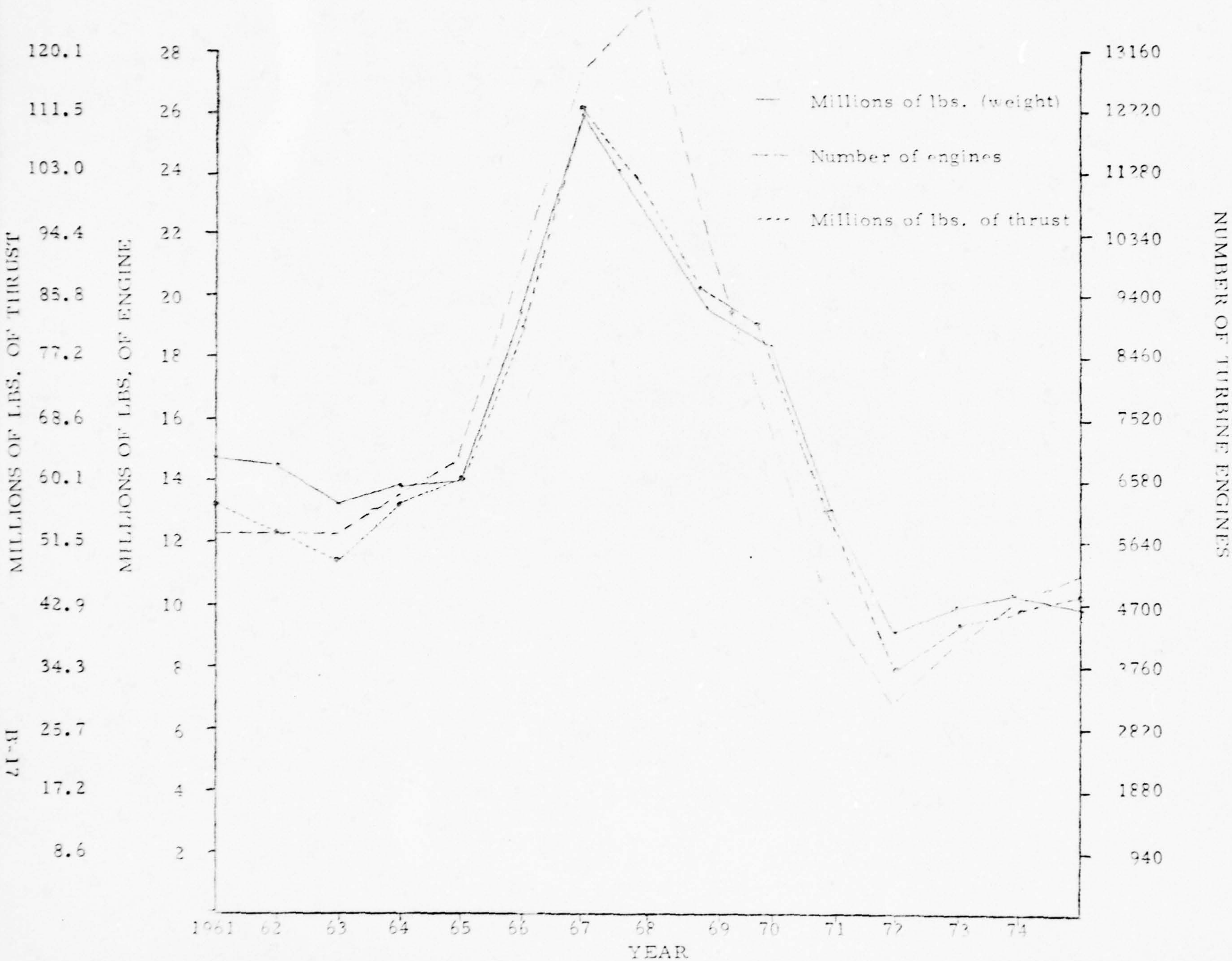


Figure B.2 - TURBINE ENGINE PRODUCTION (1961-1975)



Now in projecting engines and parts (in pounds of thrust), we use the following assumptions.

The Assumptions:

1. Percent change (1972=100) in prices

Year	Changing % price deflator for SIC 3724	Percentage change in OMB's GNP deflator	
1976	54.6 [3/]		
1977	62.6 (=54.6 + 8)		
1978	69.6 (=62.6 + 7)		
1979	75.7 (=69.6 + 6.1)	6.1	1/
1980	80.8 (=75.7 + 5.1)	5.1	1/
1981	85.1	4.3	1/
1982	89.3	4.2	1/
1983	93.5	4.2	2/
1984	97.7	4.2	2/
1985	101.9	.	2/
1986	106.1	.	2/
1987	110.3	.	2/
1988	114.5	.	2/
1989	118.7	4.2	
1990	122.9		

1/ See the long-range assumptions made by OMB, Mid-Session Review of the 1978 Budget, July 1, 1977, p.55.

2/ We assume annual increase of 4.2% which is the same as OMB's 1982 projection.

3/ The number 54.6 came from Table B.1.

2. The Market Concentration Ratio would remain at the level of the current years; i.e., $\Delta S =$ [illegible] (see p. B-6).

The assumption of $\Delta S = 20$ is untenable in the face of the fluctuating DoD procurement decisions, but in the absence of a better data on ΔS we use $\Delta S = 20$.

Using Equation (4) and the two above assumptions, we get the following results as shown in Table B.8.

Table B.8

Projected Capacity Utilization in Aircraft Engines and Parts

Year	Projected capacity utilization as % of peak capacity, (1)	Projected Capacity[1/] Utilization, (2)=(1) x (100 million lbs. thrust)
1976	50.04%	50.0
1977	66.36%	66.4 Million lbs. of AMPR WT
1978	70.81%	70.8
1979	74.68	74.7
1980	77.93	77.9
1981	80.90	80.9
1982	83.32	83.3
1983	86.00	86.0
1984	88.67	88.7
1985	91.34	91.3
1986	94.01	94.01
1987	96.68	96.68
1988	99.35	99.35
1989	102.01	102.01
1990	104.68	104.68

1/ Based on present nominal capacity of 100 million pounds of thrust.

The estimated capacity utilization in Table B.7 is steadily increasing. This trend is probable since sales of general aviation, aircrafts for aviation airlines, and exports to foreign countries would increase. The major question marks are the sales of military aircraft and foreign military sales. As shown elsewhere, U.S. government purchases of aircraft engines and parts are anywhere from 45% to 75%. If we make the assumption that the U.S. government purchases 25% less of the industry's output in the future, then we have the projections shown in Table B.9.

Table B.9

Projected Capacity Utilization with 25% Reduction in Govt. Purchases in Aircraft Engines and Parts

Year	Projected Capacity Utilization less 25% Govt. Purchases	Year	Projected Capacity Utilization less 25% Govt. Purchases
1976	37.5	1984	66.5
1977	49.8	1985	68.5
1978	53.1	1986	70.5
1979	56.0	1987	72.5
1980	58.4	1988	74.6
1981	60.7	1989	76.5
1982	62.5	1990	78.5
1983	64.5		

Another way of projecting a future relationship between GNP and aircraft engines and parts sales can use the data as shown in Table B.10. We ran the regression and obtained the following results.

Table B.10

Comparison of Aircraft Engine and Parts Sales to GNP

Year	GNP[1] (Billions of Current $)	Aircraft Engine and Parts Sales[2] (Millions of $)	Percentage of GNP
60	506	1.330	.0026
61	523	1.454	.0028
62	564	1.513	.0027
63	595	1.576	.0026
64	636	1.520	.0024
65	688	1.714	.0025
66	753	2.095	.0028
67	796	2.812	.0035
68	869	2.965	.0034
69	936	2.865	.0031
70	982	3.109	.0032
71	1063	2.346	.0022
72	1171	2.402	.0021
73	1306	2.725	.0021
74	1413	3.134	.0022
75	1516	3.386	.0023
76	1692	3.855	.0023

1 Aerospace Industries Association of America, Inc., Aerospace Facts and Figures 1977/78, p. 12.

2 Ibid., p. 31.

$$\text{Sales of aircraft engine and parts} = \underset{\substack{(268.3092) \\ (t=2.419)}}{649.0789} + \underset{\substack{(.2664) \\ (t=6.98)}}{.8594}\,(\text{GNP}) \qquad R^2 = .7645 \qquad (6)$$

By using Equation (6) and the fact that the ratio of engines and parts sales to engine thrust is fairly constant. We can develop alternative projection methods of capacity utilization in the future for the aircraft engines and parts industry.

APPENDIX C

Impact of Competition on New Capacity Buildup In the Aerospace Industry

APPENDIX C

Impact of Competition on New Capacity Buildup In the Aerospace Industry

A. Introduction

In this Appendix, we have developed a model for optimal capacity buildup for expected profit maximization among the firms in the aerospace industry. The model takes account of the profit streams of pre-buildup of capacity and post-buildup of capacity.

In discussing capacity and its utilization in the aerospace industry, there are several components to be considered. They are:

(1) manpower capacity,

(2) floor space capacity,

(3) R&D capacity,

(4) plant and equipment capacity, and

(5) working capital.

Capacity could also be measured by "production capacity" such as AMPR weight, pounds of engines, engine thrust, dollar sales, total aircrafts, etc. In addition, there are other problems such as different levels of output that can be achieved with existing facilities and manpower. For example, the OMB/DoD study of November 1976 uses three different capacity levels utilizing work-hour shift factors[1/]:

1/ OMB/DoD, Aircraft Industry Capacity Study, 17 November 1976, p. 11.

(a) Nominal One-Shift Capacity (1 shift, 40 hours)

(b) "Peak" Corporate Experience (1.4 shifts, 40 hours)

(c) Mobilization Capacity (3 full shifts, 48 hours)

It is well known that in the aerospace firms, there are frequent shifts of product lines with unusual levels of technological uncertainty. Under this circumstance the usefulness of existing capacity may be good for, say, 5 years into the future in contrast to the automobile industry's 15 years. We believe that a study of the future capacity is more relevant than one for current capacity.

The aircraft and engine industry has been increasingly concentrated into a few firms in recent years. This trend has been due to (1) increasingly sophisticated technology requiring heavy capital investment, (2) high distribution, advertising, selling costs, and (3) very restrictive government procurement regulations. For example, the aircraft and parts industry has been dominated by 7 major companies, namely:

- McDonnel Douglas,
- Lockheed,
- General Dynamics,
- Northrop,
- Boeing,
- Grumman, and
- Rockwell International.

The jet engine and parts industry is dominated by 3 major companies: the Pratt & Whitney, General Electric, and Rolls Royce. Rivalries among these companies are very fierce. Table C. 1 below shows the increasing rate of concentration.

The aerospace industry is also a most competitive industry. Competition in price is often replaced or supplemented by design and new product features, services, etc. which require newer production capacity. Very often the demand for aerospace products is below the supply capacity--i. e., there is a buyer's market. Yet, firms in the industry have to make capital investment in capacity building under great uncertainty.

We define capacity which includes inventory, new plant and equipment (which are usually embodied with new technology, scientists and engineers). In our model we describe the three options related to capacity building and how decisions should be made with regard to capacity building.

Option 1. The firm stops both sales of its present products and development of new aircraft and capacity building.

Option 2. The firm stops capacity development and sells the old products at whatever price.

Option 3. The firm may continue selling its old products while continuing its capacity buildup.

Table C.1

Competition in the Aircraft Industry

	1960			1968			1976		
FIGHTER/ ATTACK	LOCKHEED CONVAIR DOUGLAS MCDONNELL VOUGHT	REPUBLIC NORTHROP GRUMMAN ROCKWELL-LA ROCKWELL-COLUMBUS	(10)	DOUGLAS MCDONNELL VOUGHT REPUBLIC GD/FT. WORTH	NORTHROP GRUMMAN ROCKWELL-LA ROCKWELL-COLUMBUS	(9)	MACDAC VOUGHT FAIRCHILD	GD/FT. WORTH NORTHROP GRUMMAN	(6)
BOMBER	BOEING GD/FT. WORTH ROCKWELL	LOCKHEED DOUGLAS	(5)	BOEING GD/FT. WORTH ROCKWELL		(3)	BOEING GD/FT. WORTH ROCKWELL		(3)
MILITARY TRANSPORT	BOEING LOCKHEED DOUGLAS	FAIRCHILD GRUMMAN CONVAIR	(6)	BOEING LOCKHEED DOUGLAS		(3)	BOEING LOCKHEED MACDAC		(3)
COMMERCIAL TRANSPORT	BOEING DOUGLAS LOCKHEED	FAIRCHILD CONVAIR	(5)	BOEING DOUGLAS LOCKHEED		(3)	BOEING MACNAC LOCKHEED		(3)
HELICOPTER	BOEING LOCKHEED BELL SIKORSKY HUGHES	KAMAN HILLER GYRODYNE CESSNA	(9)	BOEING LOCKHEED BELL SIKORSKY	HUGHES KAMAN HILLER	(7)	BOEING BELL HUGHES	SIKORSKY	(4)

Source: OMB/DoD, Aircraft Industry Capacity Study, 17 November 1976, p. 17.

B. A Capacity Model

Suppose Π_0 is the firm's initial profit rate at time (t) = 0, before capacity buildup by rivals, and Π_1 is the reduction in profit rates of the firm after rivals' capacity buildup. Then the firm's profit rate (Π) after rivals' capacity buildup is:

$$\Pi = \Pi_0 - \Pi_1 \ . \qquad (1)$$

Denote:

$P_0 \geq 0$: the firm's profit rate as sole supplier of a new product.

$P_1 \geq 0$: the firm's profits after entry of initiators.

$P_2 \geq 0$: the firm's profits after imitating rivals.

Note that $P_1 = 0$ if entry of rivals as initiator eliminates the firm's profits.

Suppose that development of new aircraft requires \$X of additional capacity and that the capacity buildup over time can be expressed as:

$$C(t) = \int_0^t \sqrt{y(s)} \quad ds \qquad 0 \leq t \leq \min (v_1, v_2) \qquad (2)$$

where

$C(t)$ = capacity buildup over time,

$y(s)$ = capacity investment each year,

v_1 = time at which rivals' introduction of a new product, and

v_2 = time at which the firm's new product is to be marketed.

Notice that $C(t)$ is a function of $\sqrt{y}$ which is similar to an inventory optimization model. In fact, we can assume that period to period $y(t)$ is an inventory accumulation process. $y(t)$ has a composite index for quantity ordered combining (a) average annual demand, (b) replacement cost, and (c) inventory carrying cost. Equation (2) also possesses the property of diminishing marginal productivity of capacity buildup.

If a rival's new product appears at a time $v_1 > v_2$, then the effective capacity buildup in Equation (2) should be modified for $t \geq v_1$. As a consequence, the firm may alter its capacity *building schedule*, changing completion date of the buildup level from v_2 to v_3. v_3 is the firm's *another unknown* completion date. Assuming $v_1 \leq v_2$ (i.e., a rival's schedule of buildup ahead of the firm's buildup completion date), the further capacity accumulation effort will take place according to:

$$C(t) = \int_{v_1}^{t} a\sqrt{y(s)}\, ds + C(v_1), \qquad v_1 \leq t \leq v_3 \tag{3}$$

where

$a > 1$: technical advantage to the firm,

$a < 1$: technical disadvantage to the firm as a buildup follower,

$a = 1$: no one has technical advantage,

$a = 0$: no absolute technical change, and

$a = \infty$: the firm has absolute leadership or monopoly without further capacity buildup.

Since the underlying capacity function may change from Equation (2) to (3) at unknown v_1 (i.e., time at which rivals complete new capacity), it is not possible to derive a capacity development function at the minimum cost of completing the capacity building project by any given time. Hence, the firm cannot formulate an optimal expenditure plan. The stochastic nature of the realized capacity buildup is a consequence of the aerospace market uncertainty. The major sources of uncertainty in the model is (a) the firm's ignorance of whether or when some rival may introduce a new aircraft or missile, (2) arbitrary and uncertain purchase behavior of the Federal government, and (3) technological uncertainty. Even if the firm is successful in introducing a new product, the magnitude of the reward is uncertain in terms of duration of production and amount of sales and possible actions taken by rival firms. It is also the speed of surge capacity for existing products as well as for new capacity to meet production of new products.

Suppose that the firm has a subjective probability distribution $F(v_1)$ over time v_1 by which rivals will have introduced their new products or more quantity of output of old product due to their capacity buildup. Let k be intensity of rivalry in terms of the conditional probability of rivals' introduction of new product or surge capability at time v_1, then expected rival introduction time is $1/k$. The k factor reflects the intensity of rivalry with limiting cases of:

$k = 0$: the complete absence of competition,

$k = 1$: very intensive competition, and

$k = \bar{k}$: constant competitive behavior is not affected by the firm's buildup.

The firm is also uncertain about the duration of its above-normal profits, and quantity of production or as a sole supplier of an aircraft, even if it is the leader in capacity building. Suppose the conditional probability of rivals' following the firm's suit is a constant h which could be interpreted as the innovational difusion index. The values of h and k need not be equal. The value of h can be regarded, in fact, as a measure of leadership power.

The probability *distribution function* $F(v_1)$ can be expressed as:

$$F(v_1) = \begin{cases} 1 - e^{-kv_1} & \text{when } 0 \leq v_1 < v_2 \\ 1 - e^{h(v_2 - v_2) - kv_2} & \text{when } v_2 \leq v_1 \end{cases} \tag{4}$$

The first function of $F(v_1)$ in Equation (4) is when rival firms can beat the time schedule of the firm's buildup. The second function is applicable when the firm's time schedule of completion is at least ahead of rivals' schedule of buildup. Figure C.1 shows the plotting of the first function of $F(v_1)$ for various k's and $v_1 < v_2$ (i.e., rivals' buildup completion date is ahead of the firm's). If we interpret k as "concentration ratio" representing intensity of competition and v_1 as longevity of usefulness

of plant and equipment in the aerospace industry, we now have the following results.

When we assume $k = .9$ and $v_1 = 5$ years (which are realistic in the aerospace industry), the probability of rivals' capacity buildup to beat each other out is 99%.

The second function of $F(v_1)$ in Equation (4) can be interpreted as the probability, over time between v_2 and v_1 $(v_2 \leq v_1)$, of building up the capacity by rivals. Example computations using realistic assumptions are made in Table C.2. When there is no diffusion of technology (i.e., $h(v_2 - v_1) = 0$) *for given levels of competition* (k) and as the firm's completion time (or lead time) increases, the probability of rivals imitation in capacity buildup increases. When there is diffusion of technology (i.e., $h(v_2 - v_1) \neq 0$) and kv_2 (the buildup time weighted by competitive pressure) increases, the probability of rivals' buildup following the firm's suit increases very rapidly. Figure C.2 shows a partial result in Table C.2.

Shown in Table C.3 are depreciation, capital expenditures relative to the book value of selected aerospace companies in the last 10 years. These figures do not reflect investment in manpower capacity and R&D capacity. Nevertheless, they are good indicators for validating our model. Except for 1971-1972 when the aerospace industry hit the lowest point in its sales, capital expenditure are very high in the industry as depreciation rate is high, too. If there has been *no* capital investment, the book value of the assets could quickly dwindle to nothing. Judging from the magnitude

Figure C. 1

Rivals' Capacity Buildup Probability Before the Firm's Completion Date

$$F(v_1) = 1 - e^{-kv_1} \qquad (0 \leq v_1 < v_2)$$

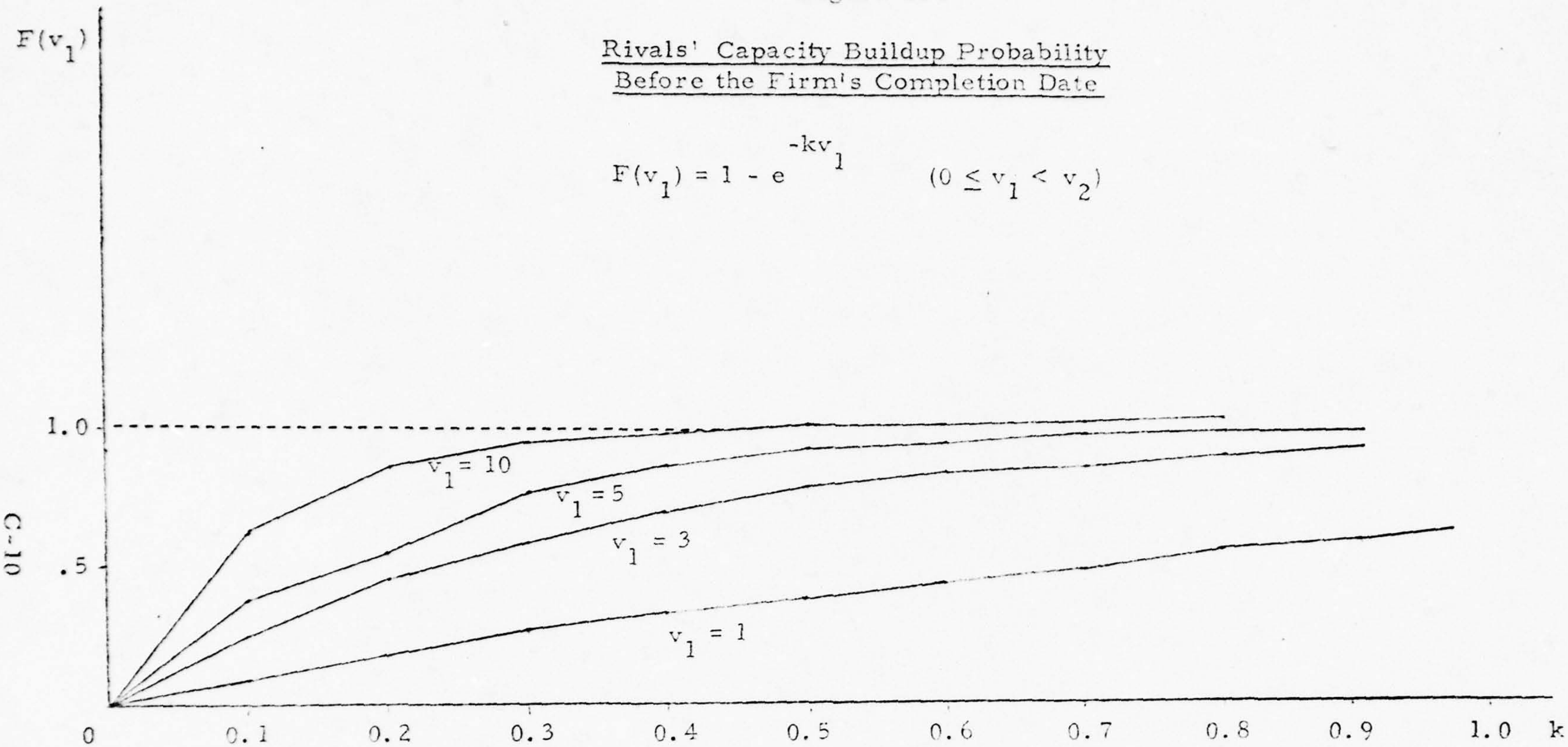


Table C. 2

<u>The Probability of Rivals' Capacity Buildup</u>
<u>After Completion of the Firm</u>

$$F(v_1) = 1 - e^{h(v_2 - v_1) - kv_2}, \quad v_2 \leq v_1$$

$h(v_2-v_1)$ / k v_2	.8 (0) $h\ (v_2-v_1)$	.8(-1)	.8(-2)	.9(-1)	.9(-2)
(.8) (1)	.551	.798	.909	.817	.926
(.8) (2)	.798	.909	.959	.713	.967
(.8) (3)	.909	.959	.982	.963	.985
(.9) (1)	.593	.817	.918	.835	.933
(.9) (2)	.835	.926	.967	.933	.973
(.9) (3)	.933	.970	.982	.973	.989
(.9) (4)	.973	.988	.994	.989	.995
(.9) (5)	.989	.995	.998	.995	.998
(.9) (6)	.995	.998	.999	.998	.999

Figure C.2

The Probability of Rivals'
Capacity Buildup After the Firm's Completion

$$F(v_1) = 1 - e^{h(v_2 - v_1) - kv_2}, \quad v_2 < v_1$$

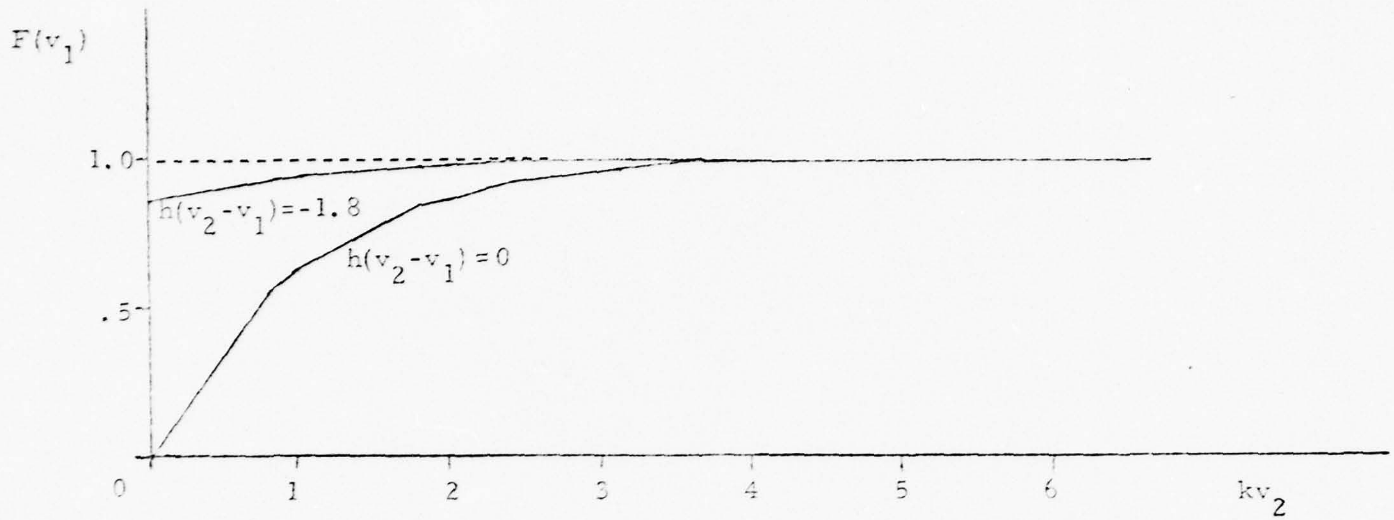


Table C.3

Depreciation, Capital Expenditures and Assets of Selected Aerospace Companies (1965-1974)

(in per share dollars)

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Depreciation (A)	$ 3.74	$ 3.95	$ 5.16	$ 6.14	$ 6.89	$ 7.22	$ 6.92	$ 6.48	$ 6.09	$ 6.51
Capital Expenditures (B)	$ 5.53	$11.95	$10.99	$ 9.52	$ 9.23	$ 7.19	$ 5.62	$ 4.92	6.46	$ 9.49
Book Value (C)	$42.36	$46.22	$50.25	$53.74	$51.85	$53.08	$54.86	$58.09	$62.86	$59.36
A/C (percent)	8.8%	8.5%	10.3%	11.4%	13.3%	13.6%	12.6%	11.2%	9.7%	11.0%
B/C (percent)	13.1%	25.9%	21.9%	7.7%	17.8%	13.5%	10.2%	8.5%	10.3%	16.0%

Note 1: The companies included are Boeing, General Dynamics, Grumman Corporation, Lockheed, Martin Marietta, McDonnell Douglas, Rockwell International, and United Aircraft.

Note 2: Per share data are expressed in terms of the Standard and Poores Price Index, i.e., 1941 - 1943 = 10.

Source: Standard and Poor's Corporation, The Outlook: Sales Gains to Taper Off by End of 1976, Composite Industry Data, p. A-31.

of depreciation rate and capital expenditures, it seems that our model of capacity building (under intense competition and rapid rate of technological obsolescence) supports what is actually taking place in the real world of the aerospace industry. Table C.3 also shows that capacity is updated technically, if we assume technology is embodied in investment.

In summary, the firm's problem is to increase profits on the current product and prevent losses resulting from rivals' introduction of new technology via new capacity investment or even from rivals' increase in maintenance of surge capacity. The firm's optimization problem involves two stages:

1. What to do if competitors buildup the capacity first.

2. How to find the firm's optimal development plan of buildup until completion of its own project or when rivals complete first (i.e., $v_1 < v_2$).

In what follows, we assume there is at least one leader in new capacity buildup, and the rest of the industry follows the leader. Suppose rivals build the capacity at time v_1 and the effective capacity buildup of the firm is $C(v_1) < \overline{C}$. $\overline{C}$ is a known level of capacity in order to be successful in introducing new product or producing increased quantity of the current product. The firm has three options. They are:

1. The firm can cease both sale of its present products and development of new capacity. This option may yield zero or negative profits for $t > v_1$.

2. The firm can stop capacity buildup and sell the old product at whatever price it can get. The discounted present value of profit from this option is

$$DP(v_1) = \frac{(\Pi_0 - \Pi_1)\, e^{-iv_1}}{i} \tag{5}$$

3. The firm may continue selling its old products while completing capacity in an optimal manner.

The third option is most likely and the firm would select during a period $(v_1 \leq t \leq v_3)$ an expenditure plan $y(t)$ and a completion date v_3 to <u>maximize</u>

$$M(t) = \int_{v_1}^{v_3} [\Pi_0 - \Pi_1 - y(t)]\, e^{-it}\, dt + \int_{v_3}^{\infty} P_2\, e^{-it}\, dt \tag{6}$$

<u>subject to</u>

$$\int_{v_1}^{v_3} \sqrt{y(t)}\; dt = \frac{(\overline{C} - C(v_1))}{a} \quad ,$$

where a is the degree of technological advantage or disadvantage as discussed previously.

The first term in the objective function represents reduced profits from the existing products less the expenditures of capacity building. The second term in the objective function is the profits when new capacity is built. The constraint in Equation (6) is from Equation (3) with $C(v_3) = \overline{C}$. A solution with $v_3 \to \infty$ means capacity stops at v_1.

Assume the firm is initiator and define

$$S = P_2 - \Pi_0 + \Pi_1 \tag{7}$$

where S increases the profit flow from new product (or increased sales with increased capacity) if the firm is an initiator of capacity buildup.

It can be shown that <u>if</u>

$$\sqrt{S}/i > \frac{\overline{C} - C(v_1)}{a} \quad , \tag{8}$$

then the solution for (6) is

$$v_3 = v_1 - i^{-1} \ln \left[\frac{1 - i\,(\overline{C} - C(v_1))}{a\,\sqrt{S}} \right] \tag{9}$$

and

$$y(t) = e^{2i(t-v_1)} \left[\sqrt{S} - \frac{i(\overline{C} - C(v_1))}{a} \right]^2 \tag{10}$$

(for $v_1 \leq t \leq v_3$).

Equation (9) gives a maximum value in (6) of

$$\text{Max } M(t) = e^{-iv_1}\left[\frac{P_2}{i} - \frac{2\sqrt{S}\,(\overline{C} - C(v_1))}{a} + \frac{i(\overline{C} - C(v_1))^2}{a^2}\right]. \qquad (11)$$

If the condition (8) does not hold, then the solution of (6) implies $v_3 \to \infty$ and maximum $M(t) = 0$. When $M(t)$ is positive it is worthwhile to complete the buildup. Thus, if completing capacity buildup after rivals' buildup is to be worthwhile, the profit stream from the new product must exceed the profit available from the old product. That is, the profit surplus must be sufficiently large relative to the remaining capacity building expenditures. From Equation (9), the remaining time to complete (i.e., $v_3 - v_1$) varies inversely with the net benefit S *after completion.*

From Equation (10), it is evident that the expenditure of buildup capacity grows exponentially with the remaining development period assuming condition (8) holds.

To find which option (listed on pp. C-14, C-15) is best, the maximum value $M(t)$ in Equation (11) from completing buildup together with condition (8) must be compared with the return from the remaining options.

Case 1. If $\Pi_0 > \Pi_1$ and the condition (8) does not hold (e.g., the old aircraft and engines are still profitable) the second option must be taken. In addition to $\Pi_0 > \Pi_1$, the condition (8) holds, we subtract the benefits ($DP(v_1)$ in Equation (5)) of discontinuing buildup from the benefits of project completion in Equation (11). It can be shown that

$$\frac{\sqrt{S} - \left[\frac{i(\bar{C} - C(v_1))}{a}\right]^2 e^{-iv_1}}{i} \geq 0 \qquad (12)$$

It is optimal to complete capacity buildup and sell the old products. Thus, the third option is viable.

Case 2. If $\Pi_1 \geq \Pi_0$, losses will be incurred on the current product prior to the completion of new buildup, and the first option is relevant. But if Equation (11) is positive (i.e., worthwhile to complete buildup according to Equations (9) and (10)) and

$$\frac{C(v_1) - \bar{C}}{a} > \frac{\sqrt{S} - \sqrt{(\Pi_1 - \Pi_0)}}{i} \quad , \qquad (13)$$

It means the accumulated buildup cost of $C(v_1)$ at the time of v_1 of competitors' completion is sufficiently large. Thus if $\Pi_1 \geq \Pi_0$, then complete buildup according to Equations (9) and (10) if and only if Equation (13) holds (note that if $\Pi_1 \geq \Pi_0$ and Equation (13) holds, then Equation (8) automatically holds). Thus depending upon the condition in Equation (13), either the first or third option chosen or the third option must be taken.

C. Validation of the Model Based on the Experience of the Aerospace Industry

In order to apply our model, the data on (1) capital expenditure, (2) sales, (3) profit margin, and (4) relative leadership position among the aerospace companies is listed in Table C.4. Because of the lack of data in the engine producing companies, we chose three airframe producing companies from the five companies for the validation purpose.

Table C.4 shows the capital expenditures made by 5 major airframe companies and their profit margins on sales. Shown in Table C.5 is Sales Records (1967 = 100), of three companies we chose for the model validation. The three companies are Boeing, Lockheed, and McDonnell Douglas.

Case 1. McDonnell Douglas Under Boeing's Leadership

Assumptions:

v_1 = 2 years of Boeing's lead time.

S = 7.65 = 3 year (1968-1970) average of McDonnell's profits (from Table C.5).

i = .07 = interest rate.

By use of condition (8), i.e.,

$$\sqrt{S}/i > \frac{\bar{C} - C(v_1)}{a} .$$

Table C.4

Capital Expenditures and Profit as Percent of Sales
(in millions of dollars)

Year	Company				
	Boeing	Grumman	Lockheed	McDonnell Douglas	Rockwell Internat'l.
1965					
$ Sales	67.80	17.00	35.89	6.88	37.63
% Profit	8.5	6.4	6.8	7.0	6.1
1966					
$ Sales	294.60	32.28	71.38	70.78	82.61
% Profit	7.6	6.1	6.4	2.6	8.1
1967					
$ Sales	246.50	30.38	69.82	44.48	92.46
% Profit	8.3	5.0	5.6	1.2	7.7
1968					
$ Sales	120.24	39.37	93.22	39.00	22.64
% Profit	8.1	5.1	5.2	6.4	8.4
1969					
$ Sales	86.91	37.27	119.03	86.88	99.28
% Profit	4.4	5.9	deficit	8.5	7.7
1970					
$ Sales	21.34	25.35	63.50	73.21	87.43
$ Profit	4.3	6.8	deficit	8.9	3.3
1971					
$ Sales	6.37	16.70	17.70	21.21	60.38
% Profit	4.2	deficit	3.7	8.5	8.5
1972					
$ Sales	9.38	10.07	2.176	23.63	119.72
% Profit	5.4	deficit	4.7	8.6	8.6
1973					
$ Sales	33.07	9.46	62.20	33.09	153.87
% Profit	3.8	5.0	4.6	8.8	8.8
1974					
$ Sales	84.34	17.66	23.10	35.01	350.10
% Profit	3.8	4.3	5.2	7.5	7.7

Source of Data: Standard and Poors Corporation, The Outlook: Sales Gains to Taper Off by End of 1976, 1975, p. A32.

Table C.5

Sales Record and Profit Indices of Boeing, Lockheed and McDonnell Douglas

Index: 1967 = 100

Company / Year	Boeing			Lockheed			McDonnell Douglass		
	Sales	Profit Margin(%)	Profit	Sales	Profit Margin(%)	Profit	Sales	Profit Margin(%)	Profit
1965	70	8.5	5.95	78	6.8	5.30	34	7.0	2.38
1966	82	7.6	6.23	89	6.4	5.70	76	2.6	1.98
1967	100	8.3	8.30	100	5.6	5.60	100	1.2	1.20
1968	114	8.1	9.23	95	5.2	4.94	123	6.4	7.87
1969	98	4.4	4.31	89	0	0	103	8.5	8.75
1970	128	4.3	5.50	109	0	0	71	8.9	6.32
1971	106	4.2	4.45	122	3.7	4.51	71	8.5	6.04
1972	82	5.4	4.43	102	4.7	4.79	93	8.6	8.00
1973	116	3.8	4.41	118	4.6	5.42	102	8.8	8.98
1974	130	3.8	4.94	140	5.2	7.28	105	7.5	7.86

Source of Data

Sales: Ibid. p. A33
Profit: Table C.4

Note: D = Deficit

Case 1a. $a = .5 \rightarrow 39.5 < \frac{294.60 - 86.88}{.5} = 415.44$

Case 1b. $a = 1 \rightarrow 39.5 < 207.72$

Case 1c. $a = 1.5 \rightarrow 39.5 < 138.48$

Case 1d. $a = 5.5 \rightarrow 39.5 > 37.77$

The above results show that it was worthwhile to follow Boeing's leadership for capacity buildup if and only if technological advantage (a) of following Boeing is fairly large.

Now we determine McDonnell's completion date of capacity building (v_3). By use of Equation (9), i.e.,

$$v_3 = v_1 - i^{-1} \ln \left[1 - \frac{i(\bar{C} - C(v_1))}{a\sqrt{S}} \right] ,$$

we estimated the values of v_3 when $a = 5.5$ and obtained $v_3 = 1.3$ years.

In short McDonnell should have followed Boeing's 1966 buildup within 1.3 years.

Next we determine what should have been the annual investment in capacity during 1967 and 1970. Using Equation (10) and $a = 5.5$, we arrive at:

$y(t) = \$4.02$ million.

Finally, by use of Equation (11) we derive maximum annual profit, $M(t)$, after following Boeing's lead (with $a = 5.5$ and $v_1 = 2$) for the 1967-68 at

Max $M(t) = \$1.15$ million/year.

Case 2. Lockheed Under Boeing's Leadership

Assumptions:

$v_1 = 2$ years of Boeing's lead time.

$S = 1.65 = 3$ year (1968-1970) average of Lockheed profits.

$i = .07 =$ interest rate.

By use of condition (8), i.e.,

$$\sqrt{S}/i > \frac{\bar{C} - C(v_1)}{a}, \quad \text{we have}$$

$$a = 1 \quad 18.35 < \frac{294.60 - 119.03}{1} = 175.57,$$

$$a = 10 \quad 18.35 > 17.56.$$

The condition indicates that Lockheed should have had enormous technological advantage of following Boeing, i.e., $a = 10$.

By use of Equation (9), i.e., v_3 is not defined. That is, $v_3 \to \infty$ (or no investment at all).

Equation (10) with $a = 10$, $y(t) = -\$1.9$ million per year.

And the maximum profit for 1967-68 is zero; i.e.,

$\text{Max } M(t) = 0.$

APPENDIX D

Survey Instrument

INSTRUCTIONS

The data requested refers to operations of your company devoted primarily to engine production. The data requested covers the time period 1961-1975. Complete data for this time period is, of course, desirable in terms of analyzing industry trends. In the case where providing data for each year is extremely inconvenient, data can be provided for the highest and lowest sales year in this time period, and for 1975 only.

Table D.1

Annual production data for each type of engine (aircraft or non-aircraft use) is desired for the years indicated. Location of production refers to the plant location of final assembly. Please also provide information on those engines for which substantial R&D was done or is in progress although no production has occurred.

Table D.2

Application and type refers to the prime application (aircraft, helicopter, marine, trucks, etc.) and the particular type of engine (Axial Flow Turbojet, Turbofan, etc.) For those engines mentioned in Table One, provide information on this sheet.

The approximate price range should be given in 1975 constant dollars or indicate year for which estimate is made.

Total number sold indicates total number sold through 1975.

Table D.3

The current lead time from order is the time from signed contract to delivery date. Please indicate in column 2 the best lead time acheived in past production runs. Please indicate in column 3 the actual in-house production time, i.e., the time, once all parts bought outside have been received, that is required until final delivery.

Table D.4

For this table if data for each time period is difficult to obtain, you may indicate current lead times (74-76), and the shortest and longest lead time experienced in the 62-75 time frame only.

Table D.5

Note that sales are for engines only excluding spare parts, engine rebuilding and modifications. Please indicate for the total only the mix of domestic commercial, domestic military, foreign military and foreign commercial sales.

Table D.6

Please indicate sales data for spare and replacement parts, engine rebuilding and modifications. Please indicate for the total only the mix of of domestic commercial, domestic military, foreign military and foreign commercial sales.

Table D.7

Please indicate total backlog excluding spare parts, rebuilding and modifications. Break total out for four categories only.

Table D.8

Please indicate total backlog for spare parts and replacement, modifications or rebuilding.

Table D.9

Pleas indicate projection of total sales including backlog for both engine production, spare parts, rebuilding and modifications. Break out total for the four categories indicated.

Table D.10

Provide the total floor space, acquisition cost of land and buildings, and accrued depreciation annually for government and company owned facilities. Provide the average age of buildings and machines or tools for 1975 only. Weight the age of each building, madhine or tool by acquisition cost in doing the average calculation for 1975.

Indicate at bottom of sheet or on additional sheets any clarification necessary for depreciation method used or basis for utilization percentage for floor space and machinery. We realize that estimates may be only approximate.

Table D.11

Average annual employment is number of employees in each classification. Under labor utilization, provide the number of hours in each shift, number of days for each shift, and utilization as a percentage of total employment for each shift. For instance, 55 per cent of total employees might be first shift, 25 second shift, and 20 per cent third shift.

Table D. 12

Provide total floor space by location for all company facilities utilized primarily for engine production for 1975 only.

Table D. 13

The cost information should be given for only the engine division of your company, or for the smallest unit which contains the engine division for which such data is kept.

A general cost format applicable to all companies is difficult to construct. If your cost structure fits into the format of Table D. 13, provide this information. On the other hand, your accounting system may have a format more easily tabulated but different than Table D. 13. If so, please provide information similar in level of detail and disaggregation to Table D. 13. We also request you to provide an income and balance sheet for the same division or unit for 1975.

Table D. 14

Include all activities in the RDT and E area.

Table D. 15

Provide all information on parts, materials or subcontracts procured outside U. S.

TABLE D.1

HISTORICAL, ANNUAL ENGINE PRODUCTION DATA

Engine Type	Location of Production	1961	62	63	64	65	66	67	68	69	70	71	72	73	74	1975
Total																

TABLE D.2

ENGINE CHARACTERISTICS

Engine	Application and Type	Military or Civil	Power Class	Weight	Approximate Price Range	Year of Initial R&D	Year of First and Last Production	Total Number Sold Thru 75

TABLE D.3

CURRENT LEAD TIMES FOR ENGINE TYPES

Engine Type	Current Lead Time from Order	Best Lead Time Achieved in Past	Actual In-house Production Tim

TABLE D.4

HISTORICAL AVERAGE LEAD TIMES FOR CERTAIN CRITICAL ITEMS

	62-64	64-66	66-68	68-70	70-72	72-74	74-76
Castings							
Forgings							
Controls							
Fabricated and Machined Parts							
Gears and Gearboxes							
Bearings							
Configuration Hardware							
Others (List)							
Alloys							
Extrusions							

TABLE D.5

HISTORICAL SALES DATA FOR ENGINES EXCLUDING SPARE PARTS, REBUILDING AND MODIFICATIONS

Engine Type		61	62	63	64	65	66	67	68	69	70	71	72	73	74	1975
OVERALL	U.S. MIL.															
	U.S. COM.															
	FOR. MIL.															
	FOR. COM.															

TABLE D.6

HISTORICAL SALES DATA FOR SPARE PARTS, REBUILDING AND MODIFICATION

Engine Type		61	62	63	64	65	66	67	68	69	70	71	72	73	74	1975
OVERALL	U.S. MIL.															
	U.S. COM.															
	FOR. MIL.															
	FOR. COM.															

TABLE D.7

CURRENT BACKLOG OF SALES (Excluding spare parts, rebuilding, modifications)

Engine Type		1976	1977	1978	1979	1980	1981
Total	Military - U.S.						
	Commercial - U.S.						
	Foreign Military						
	Foreign Commercial						

TABLE D. 8

CURRENT BACKLOG OF SALES FOR SPARE PARTS, REBUILDING AND MODIFICATIONS

Engine Type		1976	1977	1978	1979	1980	1981
Total	Military - U.S.						
	Commercial-U.S.						
	Foreign Military						
	Commercial - For						

TABLE D.9

PROJECTED TOTAL SALES

Engine Type		1976	1977	1978	1979	1980	1981
Total	Military - U.S.						
	Commercial - U.S.						
	Foreign Military						
	Foreign Commercial						

TABLE D. 10

CAPACITY DATA

	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Total Floor Space (company owned) (Unit) ______															
Acquisition cost of land and buildings															
Accrued depreciation of land and buildings															
Average age of buildings															
Total Floor Space (government owned) (Unit) ______															
Acquisition value of land and buildings															
Average age of buildings															
Rough Utilization Percentage of Floor Space															
Acquisition Value of Tools and Machinery															
Government owned															
Company owned															
Accrued Depreciation on Tools and Machinery															
Company owned															
Average Age of Tools and Machinery															
Government owned															
Company owned															
Rough Utilization Percentage of Tools and Machinery															

TABLE D. 11

EMPLOYMENT (LABOR UTILIZATION)

		61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Average Annual Employment																
Production Workers																
Technical and Managerial																
Total employment																
Labor Utilization (Annual Average) for Production Workers																
First Shift	Hours															
	Days															
	Utilization															
Second Shift	Hours															
	Days															
	Utilization															
Third Shift	Hours															
	Days															
	Utilization															
Average Wage Data																
Production Workers																
	First Shift															
	Second Shift															
	Third Shift															
Technical/Engineering																
Overall Average Make/Buy Ratio for Engine Production																

TABLE D. 12

CAPACITY DATA

	75
Total Floor Space by Location	
Location __________	
Government owned	
Company owned	
Location __________	
Government owned	
Company owned	
Location __________	
Government owned	
Company owned	
Location __________	
Government owned	
Company owned	
Location __________	
Government owned	
Company owned	
Location __________	
Government owned	
Company owned	

TABLE D. 13

ANNUAL COST STRUCTURE

	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Direct Production Labor															
Direct Materials, Vendor and Subcontractors															
Fringe															
Overhead (Total)															
Direct Labor															
Facility related cost and depreciation															
Machinery and tool related cost and depreciation															
New Business, Proposal writing, Marketing															
Other															
General and Administrative (Total)															
Direct Labor															
Other															
Total Costs and Expenses															
Income (Earnings) Pre-tax															
Interest															
After Tax Earnings															
Sales (Millions)															

TABLE 14

ENGINE DIVISION RESEARCH DEVELOPMENT, TEST AND EVALUATION FUNDS

	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Government Supported														
Company Supported														

TABLE D.15

FOREIGN SUPPLIER OR SUBCONTRACTORS FOR MILITARY ENGINES

Name of Foreign Supplier or Subcontractor	Country	Item and Engine	Dollar Volume (1975)

The Department of Defense would like to initiate procurement policies which keep engine cost low, maintain a surge capacity for emergencies and also maintain pre-eminence of U.S. firms in engine technology. As you view the next five years for your company and the industry, could you comment on the extent to which each of the following will present problems? Be as specific as possible about the nature of the problem.

1) Ability to recruit, train or replace production skills

2) Ability to recruit, train or replace key technical and managerial skills

3) Obtaining needed capital for aircraft engine division

4) Maintaining cost competitiveness with foreign engine makers

5) Maintaining technical competitiveness with foreign engine makers

6) *Protecting U.S. technology in engines from foreign engine makers*

7) Uncertainty in timing and amount of commercial sales

8) Uncertainty in timing and and amount of military sales

9) Possible material shortages (which materials)

10) Lengthening lead times from subcontractors

11) Maintaining reliable subcontractors

12) Having inadequate capacity

13) Having excess capacity

others (list and comment)

Please list those you consider most severe in rough rank order

1.

2.

3.

4.

5.

What new or changed DOD procurement policies do you see as contributing to the goals mentioned above as well as averting some of the central problems mentioned above?

APPENDIX E

1966 and 1975 Data on Federal Procurement In Area A-1B Aircraft Engine By Company

TABLE E.1

Top 61 Companies in DOD Sales in [1/]
Aircraft Engines 1966

	Company	DOD Engine Sales [1/] (000)
1	United Aircraft Corp. [1]	789,300
2	GE [1]	622,592
3	Avco Corp.	294,904
4	GM Corp. [1]	160,573
5	Curtis Wright Corp. [1]	69,046
6	Canadian Commercial Corp.	25,130
7	Continental Aviation and Engineering Co. [1]	20,209
8	Garrett Corp. [1]	16,840
9	Bendix Corp.	12,249
10	Chandler Evans Corp.	10,931
11	Boeing Co.	8,649
12	International Harvester co.	5,129
13	Marquardt Corp. [3]	4,243
14	Sunstrand Corp.	4,142
15	Kaman Aircraft Corp. [3]	2,660
16	Continental Motors Corp.	2,099
17	Holley Carguretor Co.	2,065
18	N. American Aviation Inc. [1]	1,807
19	Champion Spark Plug Co.	1,273
20	Borg Warner Corp.	1,240
21	Woodward Governor Co.	1,128
22	Airmotive Engineering Corp.	1,108
23	Thiokol Chemical Corp. [3]	1,107
24	Texas Instruments	994
25	Lear Siegler Inc. [1]	955
26	United Air Lines Inc.	944
27	Pratt and Whitney Inc. [3]	850
28	Kidd and Walter and Co. Inc.	756
29	General Applied Science Lab [3]	748

	Company	DOD engines Sales
30	Sperry Rand Corp.	747
31	Vickers Inc.	743
32	Atlas Corp.	729
33	General Lab Assoc. Inc.	705
34	United Aircraft Products Inc.	702
35	Stein Seal Co.	701
36	Jet Avion Corp.	685
37	American Brake Shoe Co.	644
38	Aircraft Porous Media Inc.	641
39	Vapor Corp.	609
40	Trans Sonics Inc.	607
41	Cal Val R&D	541
42	Mich. Dynamics Inc.	536
43	Gilco Inc.	500
44	Franklin Engine Co. Inc.	497
45	Cooperative Industries Inc.	467
46	Aerokits Inc.	466
47	Aircraft Supply Co. Inc.	455
48	Thompson Ramo Wooldridge Inc.	450
49	S Kif Industries Inc.	442
50	Jervis Corp.	435
51	Air Logistics Corp.	434
52	Wilpac Manufacturing Co.	421
53	Westinghouse Electric Corp. [2]	419
54	Parker Hannifin Corp.	416
55	Lockheed Aircraft Corp. [1]	413
56	Koppers Co. Inc.	356
57	Ford Motor Co.	355
58	Northrop Corp.	353
59	Pacific Airmotive Corp.	352
60	Teleflex Inc.	325

	Company	DOD Engines Sales
61	Whittaker Corp.	315

1/ Sales in 10-C Code A-1B (Aircraft Engines and Related Spares and Parts)

3- Substantially all R&D

2- Greater than 50% R&D

1- 10-50% R&D

TABLE E.2

Top 71 Companies in DOD Sales in Aircraft Engines 1975 1/

	Company	DOD Engine Sales 1/ (000)
1	United Technologies Corp. [1]	1,055,688
2	General Electric Co.	544,351
3	General Motors Corp.	218,956
4	Avco Corp.	40,332
5	Rolls Royce Ltd.	17,010
6	Garrett Corp. [1]	12,397
7	Teledyne CAE [1]	12,157
8	Bendix Corp.	11,243
9	Williams Research Corp. [2]	10,449
10	Curtiss Wright Corp.	7,861
11	Sunstrand Corp.	7,241
12	United Aircraft of West Virginia	4,991
13	Canadian Commercial Corp.	4,317
14	Lockheed Aircraft Corp. [2]	3,615
15	Teledyne Inc.	3,178
16	Chandler Evans Corp.	2,504
17	Wilson Machine Co. Inc.	1,890
18	Gary Aircraft Corp.	1,838
19	Alamo Aircraft Supply Inc.	1,673
20	Teledyne Industries Inc.	1,637
21	Airmotive Engineering Corp.	1,531

22	Colt Industries Inc.	1,376
23	Aircraft Supplies	1,192
24	Lucas Aerospace Std.	1,020
25	TRW Inc.	942
26	Cooper Airmotive Co.	864
27	Ferrotherm Co.	858
28	General Mfg. Corp.	839
29	Electro Methods Inc.	785
30	Delavan Mfg. Co.	760
31	Woodward Governor Co.	756
32	Pneumo Corp.	756
33	Kidde Walter and Co. Inc.	753
34	Simmonds Precision Products	683
35	Textron Inc.	592
36	Associated Aerospace Activities	554
37	U.S. Small Business	550
38	Texas Instruments Inc.	531
39	Bieken Mfg. Co.	513
40	Lear Siegler Inc.	491
41	Lord Corp.	476
42	Teleflex Inc.	470
43	Koppers Co. Inc.	467
44	Aircraft Porous Media Inc.	464
45	Hansen Engineering and Mach. Co.	456

46	SKF Industries Inc.	446
47	Sperry Rand Corp.	440
48	Lytron Inc.	429
49	Parker Hannifin Corp.	383
50	Gould Inc.	377
51	Stein Seal Co.	375
52	Vogue Instrument	315
53	Atlas Corp.	303
54	Abex Corp.	292
55	Livingston Industries Inc.	283
56	Lenox Instrument Co.	278
57	Fenwal International Inc.	268
58	International Harvester Co.	266
59	Jet Avion Corp.	254
60	Champion Co.	253
61	Boeing Vertol Co.[1]	252
62	Stow Mfg. Co.	243
63	Arkwin Industries Inc.	236
64	Boeing Co.	236
65	Bendix Autolite Corp.	225
66	Roard CF Welding and Engr. Co.	223
67	Superior Air Parts Inc.	223
68	Lynch Corp.	212
69	Bailey HN & Associates	210

70	Norwood Precision Products Inc.	205
71	Dyna Empire Inc.	204

1/ Sales in 10-C Code A-1B (Aircraft Industry)

3- Substantially all R&D

2- Greater than 50% R&D

1- 10-50% R&D